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# SIZE DISTRIBUTION OF THE WHITE RIVER ASH, YUKON TERRITORY

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by

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## ABSTRACT

The White River Ash is a recent tephra-fall covering a major portion of the southern Yukon Territory. The deposit has a bi-lobate form with the axis of the major lobe trending east and the axis of the secondary lobe trending north from an origin somewhat west of the International Boundary near 61° 30' latitude. Samples from 66 locations and thickness observations from 132 locations were taken along the Alaska Highway and along the roads between Whitehorse, Mayo, Dawson City and Tetlin Junction. The isopach map of the deposit published by Bostock (1952) was modified to fit the new thickness observations.

The grain size distribution was determined for the main lobe of the White River Ash by sieving and pipette analysis. This distribution is different from that expected from a theoretical modal in that the modes of equal phi values are distributed about the axis so as to form V-shaped isopleths pointing away from the origin. By using the method of Knox and Short (1963) the location of the volcanic vent was calculated to be near Mount Bona, at least 20 miles west of Mt. Natazhat, which previous authors had proposed to be the source; the energy of the explosion was equivalent to 33.7 kilotons of TNT; and the mean and maximum heights of the cloud were 16.8 and 22.6 kms. It is concluded that the results of the study are encouraging enough to warrant further study of tephra-falls in a similar manner.

## ACKNOWLEDGEMENTS

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# INTRODUCTION

The purpose of this study was to apply a theoretical model of fallout deposition to a recent volcanic "ashfall" to see if it explains the observed phenomena, and to assess the likelihood that it will provide a valuable tool in the interpretation of ancient falls.

An examination of the literature of volcanic deposits soon discloses the confusion that exists when referring to clastic ejecta. Dust, ash, sand, lapilli, scoriae, pumice, bombs, and blocks are the descriptive terms most commonly encountered, but the meanings of these terms have not been closely defined. A further difficulty is encountered when trying to find an appropriate collective term.

To refer to the ejecta collectively Thorarinsson's (1954) term "tephra" is used. His definition for tephra is "All the clastic volcanic material which during an eruption is transported from the crater through the air". Tephra was first used by Aristotle in his account of an eruption on the island Hiera (Vulcano), probably the oldest description of a tephra-fall preserved in European literature (Meterologicorum LiberII, Cap VIII, 19, in Bibl. Script. Graec. 6, vol, III, Paris, 1854). Thorarinsson's arguments for the use of the term are: (1) it does not suggest any grain size fraction or ash in the chemical sense; (2) it is suitable for international use; (3) it is in linguistic harmony with lava and magma.

Recent advances made by meteorologists in studies of fallout from near-surface nuclear explosions has opened a new field in volcanology by placing the mechanics of tephra deposition on a sound mathematical basis. It will probably require many years of research on recent volcanic deposits before confidence in experimental results obtained from studies of this type will be attained. It is believed the present study, the most thorough of its type known to the author, is a step in this direction.

## PREVIOUS INVESTIGATIONS

### Location and size of the Deposit

The White River Ash lies within a few inches of the soil surface over most of the southern Yukon Territory and a portion of western Alaska. The deposit has a bilobate shape with the main lobe elongated in an east-west direction extending from the International Boundary eastward into the western portion of the District of MacKenzie, a distance of over 450 miles. A secondary lobe extends northward elongated parallel to the International Boundary for approximately 250 miles.

The accompanying map (figure 1) adapted and modified somewhat from that published by Bostock (1952) shows the areal extent of the deposit. The isopach labelled "approximate limit of noticeable deposit" outlines the area covered with more than one-quarter of an inch of tephra. It is thought that an amount less than this falling on a vegetated terrain would be unlikely to leave a recognizable layer. From modern analogies the actual tephra-fall was probably over a much wider area than represented by this limit.

Owing to the conspicuous nature of the White River Ash in many regions, it was noted at a relatively early date by explorers in the territory. Schwatka (1883) was the first to do so when he described it along the banks of the Yukon River between Teslin Lake and Fort Selkirk. Shortly after this, in 1887, it was further described and its known extent expanded by Dawson of the Geological Survey of Canada.

An expedition by Hayes (1892) from Fort Selkirk to White River added more information. In 1898 and 1899 Brooks explored and did geological reconnaissance around the headwaters of the White and Tanana rivers and recorded many observations on the tephra. Moffit and Knopf (1910) in their report on the Nabesna and White River basins included a petrographic description of the ash.

Capps, in 1914, on his second expedition into this area spent some time studying the deposit which had sparked his interest on his first expedition in 1908. He compiled all the observations which had been made up to that time and published an isopach map of the deposit which showed only one lobe. From his observations of thickness and distribution of particle sizes he estimated the source to be near Mt. Natazhat the peak of which is approximately 4 miles west of the International Boundary almost on the 61° latitude. He was the first to refer to the deposit as the White River Ash although he did not actually propose this as the name of the deposit.

The next comprehensive report on the tephra deposit was published by Bostock of the Geological Survey of Canada in 1952. He compiled the information of many observers including himself, and published a new isopach map which showed the bi-lobate shape of the deposit.

Berger (1960) added some more observations and recalculated the volume of the deposit. Fernald (1962), and Stuiver, Borns and Denton (1964) have recently done radiocarbon dating of the deposit.

Most of the material in the above-mentioned reports is purely descriptive. Briet petrographic descriptions have been given by Knopf (1910) Berger (1960) and Stuiver, Borns, and Denton (1964). Only one sample was size-analysed; this was done by Keele (in Capps, 1915) on a sample collected from the Gravel River over 400 miles from the probable source of the tephra. He used 60, 80, 100, and 200 mesh wire screens, but found that 72% of the tephra passed through the finest screen. From a microscopic examination he estimated the average size of the fine fraction to be 0.01 mm.

Apart from these descriptions five authors have calculated the volume of the deposit with varying results. Dawson (1887) was first with a published figure of 1.18 cubic miles for the extent of the tephra as he knew it. Hayes

(1892) was next with an estimate of 165 cubic miles. To arrive at this rather large figure he assumed that the deposit was the shape of an inverted cone, which is not the case. Capps (1914) from his isopach map calculated a figure of 10 cubic miles of tephra. These first three estimates do not include a reduction to solid rock of similar composition as do the following two estimates. Bostock, using his improved isopach map and making porosity corrections, calculated a volume of 2.12 cubic miles of andesite. For comparison with the earlier figures this was reduced from a calculated 12.5 cubic miles of unconsolidated tephra. To reduce this figure he assumed a porosity of 65% for the pumice particles and an interspace porosity of 50%.

Berger (1960) used Bostock's map in his calculation, but changed some of the thickness in the region of maximum thickness (Mt. Natazhat). From his own experience in the region, the thicknesses of 100 to 300 feet reported by Hayes, Brooks, and Capps were believed to be in error. He found the maximum thickness to be 10 feet. Assuming a maximum porosity of 55% for the large pumice fragments (measured from fragments up to 4 inches in longest dimension) and a maximum interspace porosity of 50%, Berger obtained a volume of 1.4 cubic miles of solid dacite. This he concluded is a minimum value as the porosity of the pumice fragments decreases with decreasing grain size. He felt that a reasonable estimate would be 2.15 cubic miles.

These calculations of volume show that the eruption was of considerable magnitude and of similar size to other large tephra-falls in the volcanic belt of the Pacific Ocean. Katmai in 1912, and Krakatoa in 1883, for example, were said to have erupted material equivalent to 5 cubic miles of magma (Capps, 1915).

The only published size analysis of a tephra-fall is that of Thorarinsson (1954) which does not show the complete distribution of particle sizes as he sampled only from the axial region of the lobe, and did not analyze the material finer than the 200 mesh sieve. As a result, most of the theory used in the present study

has come from studies of nuclear explosions and their radioactive fall-out, which are comparable to volcanic explosions and their tephra "fall-out".

## Age of the Deposit

The White River Ash lies near or at the surface and is part of the soil profile. It is a very persistent layer particularly in the area covered by the main lobe. Its relationship to the various soil horizons has been worked out mainly in the low lying areas along the Alaska Highway. In the rugged and topographically higher regions to the north, complications arise from the presence of steep slopes and incomplete soil profiles. On some of the lower mountain slopes, notably in the Wrangell Mountains, the tephra is at the surface and from a distance is easily mistaken for snow. The tephra always bears a close relationship to the present topography and covers everything down to the low terraces of streams. All of these factors indicate that the tephra is very recent and is in fact much younger than the glacial deposits from the last period of glaciation.

A summary of the soil horizons recognized by MacNeish (1960) in the Southern Yukon will aid in clarifying the relations of the bed in question (Table 1). The whole area is covered by a thick humus which has developed in the last one thousand years. This overlies an area of brown loess which at Kluane Lake is called the Slims' River Silts, which in turn overlie the White River Ash. Underneath the Ash is a pink soil which is probably a mature profile representing the first forest invasion, which may have started during the post glacial optimum around 5000 B.C. The pink soil is basically loess turned pink by the maturing of the profile by forest cover. Below this is a wind blown sand or loess which probably formed during the period following the retreat of the last glacier and before the forest invaded the area between 7000 and 5000 B.C.

Several attempts to arrive at an absolute age for the White River Ash

TABLE 1

CULTURE COMPLEXES OF SOUTHERN YUKON

| COMPLEX | SOIL PROFILE | AGE | TRADITION OR AFFILIATION |
|---|---|---|---|
| BENNET LAKE | HUMUS | 1000 | UNKNOWN BUT NOT WITH NORTHWEST INTERIOR MICRO-BLADE TRADITION |
| AISHIHIK | SLIMS RIVER SILTS AND LOESS | 1519$\pm$150 | |
| TAYE LAKE 2500-4000 | WHITE RIVER ASH | | NORTHWEST INTERIOR MICRO-BLADE TRADITION (not derived from Agate Basin or Yuma Traditions) |
| | LIGHT BROWN LOESS AND/OR UPPER RED LOESS | | |
| GLADSTONE | | 5000 | |
| LITTLE ARM 5000-7000 YRS | LOWER RED SOIL OR LOESS | 7000 | |
| CHAMPAGNE 6000-8000 YRS | PALE SAND OR LOESS | | AGATE BASIN OR YUMA TRADITION |

have been made. The first was by Capps (1915) who put forth a date of eruption of approximately 500 A.D. He arrived at this figure by calculating the rate of peat accumulation in an area and then measuring the thickness of peat over the tephra. No other determinations of age were made until 1951 when Johnston, who had carried out an archaeological survey along the Alaska Highway in 1944 and had collected some charcoal samples from the tephra, had these samples radiocarbon dated. An average age of 1519$\pm$ 150 years was reported for them. This would place the eruption in a period around 430 A.D. It should be noted that this agrees very closely with Capps' determination, but this agreement was not commented on by Johnson. On the contrary this radiocarbon date was not well received. Even Johnston, the collector of the samples, expressed doubts by stating "judgement on the validity of this date must be reserved as there is nothing to compare this date to". Another archaeologist, H. B. Collins (1953), also expressed doubts, feeling that the tephra should be "considerably older".

The more recently published archaeological report by MacNeish (1960) at first appearance would seem to have no argument with Johnston's dates, and in the report the age of 1519$\pm$ 150 years is given for the White River Ash. However, in his concluding summary MacNeish states (p. 48) "Thus it seems reasonable that ... the late horizons of the North West Micro-blade Tradition may be placed in the period between 2,500 and 4000 years ago". This conclusion was based on dates from central British Columbia and the west end of Great Bear Lake and suggests some contradiction in that on the preceding page he classifies artifacts found in the lower portion of the White River Ash as belonging to this tradition (in this case the Taye Lake complex).

Additional radiocarbon ages provided by Fernald (1962) from the Tanana River valley in Alaska of 1635$\pm$ 80 years B.P., and by Stuiver, Borns, and Denton (1964) of 1425$\pm$ 50 years for the Klume Lake area, leave little doubt of the surprising degree of correctness of Capps original calculation.

## SAMPLE COLLECTION AND THICKNESS DETERMINATIONS

Samples were collected in July 1963 by Drs. F. A. Campbell and J. F. Lerbekmo along the Alaska Highway and the road from Whitehorse to Mayo, Dawson and Tetlin Junction. Observations of thicknesses and collection of samples were normally made at intervals of five miles wherever the tephra deposit was noticeable. In areas where changes of thickness were abrupt additional readings were made as required. When sampling, care was taken to include the whole bed in the sample, which was usually not difficult as the ground was wet and the bed held together well. When there was apparent stratification within the bed each stratum was collected as a separate sample. The amount of material collected from each location averaged about three pounds, although this varied considerably. A total of 134 observations of thickness were made, and 137 samples, including 5 cores, were collected from 66 locations. The samples are listed in table 2, showing the re-numbering of samples for easy reference.

With the additional observations of thickness made during the collection of samples, an attempt was made to improve Bostock's (1952) isopach map, but it was found that the necessary changes were small (figure 1). The isopachs on the northern edge of the western lobe were moved closer together and some changes were made in the area between the two lobes. The northern lobe was changed considerably but the isopachs do not form a very consistent pattern, and it is suspected that the tephra bed in these areas has been somewhat eroded.

The thickness of the tephra layer in the two lobes has been plotted as a function of the distance from Mt. Natzhat on semi-logarithmic paper (figure 2). The plots approximate straight lines fairly closely, as was found to be the case by Thorarinsson (1954) for the Hekla eruption. Thorarinsson used this kind of a plot to calculate the volume of his tephra bed, as it defines the surface between isopachs.

TABLE 2

WHITE RIVER ASH SAMPLES

| Sample No. | No. of Specimens | Ref. No. | Thickness in inches | Sample No. | No. of Specimens | Ref. No. | Thickness in inches |
|---|---|---|---|---|---|---|---|
| WM 2.5 | 2 | 1 | 1 | 1087 | 1 | 32 | 2 |
| 6 | 1 | 2 | 1 | 1094 | 1 | 33 | 3 |
| 13.5 | 1 | 3 | 1 1/2 | 1102 | 3 | 34 | 3 1/2 |
| 26.5 | 1 | 4 | 1 1/2 | 1108 | 2 | 35 | 4 1/2 |
| 37 | 3 | 5 | 3 1/2 | 1113 | 3 | 36 | 6 |
| 42 | 1 | 6 | 3 1/2 | 1118 | 1 | 37 | 6 |
| 47 | 3 | 7 | 3 1/2 | 1123 | 3 | 38 | 6 1/2 |
| 52 | 4 | 8 | 5 | 1128 | 1 | 39 | 9 1/2 |
| 57 | 4 | 9 | 5 | 1133 | 3 | 40 | 10 |
| 62 | 2 | 10 | 6 | 1138 | 4 | 41 | 15 |
| 67 | 1 | 11 | 5 | 1143 | 1 | 42 | 21 |
| 72 | 1 | 12 | 5 1/2 | 1149 | 5 | 43 | 21 |
| 77 | 1 | 13 | 7 | 1151 1/2 | 5 | 44 | 13 |
| 82 | 1 | 14 | 6 1/2 | 1156 | 6 | 45 | 3 1/2 |
| 87 | 4 | 15 | 6 | 1157 | 1 | 46 | ? |
| 92 | 3 | 16 | 7 | 1202 | 1 | 47 | 2 1/2 |
| 97 | 1 | 17 | 6 | 1247 | 3 | 48 | 5 |
| 102 | 2 | 18 | 8 | 1257 | 3 | 49 | 6 1/2 |
| 107 | 1 | 19 | 6 | 1267 | 4 | 50 | 4 1/2 |
| 112 | 1 | 20 | 6 1/2 | 1277 | 3 | 51 | 4 |
| 117 | 1 | 21 | 7 | | | | |
| 127 | 1 | 23 | 9 1/2 | DT-40 | 1 | 53 | 1 1/2 |
| 132 | 6 | 24 | 11 | DT-50 | 1 | 54 | 1 1/2 |
| 137 | 1 | 25 | 11 | DT-73 | 1 | 55 | 2 |
| 142 | 3 | 26 | 7 1/2 | DT-100 | 1 | 56 | 4 |
| 147 | 1 | 27 | 3 | DT-110 | 1 | 57 | 2 1/2 |
| A. 837 | 2 | 62 | - | DT-130 | 1 | 58 | 1 |
| A. 951 | 2 | 28 | 1 | 135 | 2 | 59 | 2 |
| 1006 | 1 | 29 | 1/2 | 150 | 2 | 60 | 2 1/2 |
| 1077 | 1 | 30 | 1 1/2 | 160 | 1 | 61 | 1 1/2 |
| 1082 | 1 | 31 | 1 1/2 | A 975 | 1 | 63 | 1/2 |
| | | | | A 991 | 1 | 64 | - |
| | | | | AISH 417 | 1 | 65 | 1 |
| | | | | A 1072 | 1 | 66 | 1 |

1. WM - Mileages on Whitehouse - Mayo highway.
2. A - Mileages on Alaska highway.
3. DT - Mileages between Dawson City and Tetlin Junction.
4. AISH - Mileages on Aishihik highway.

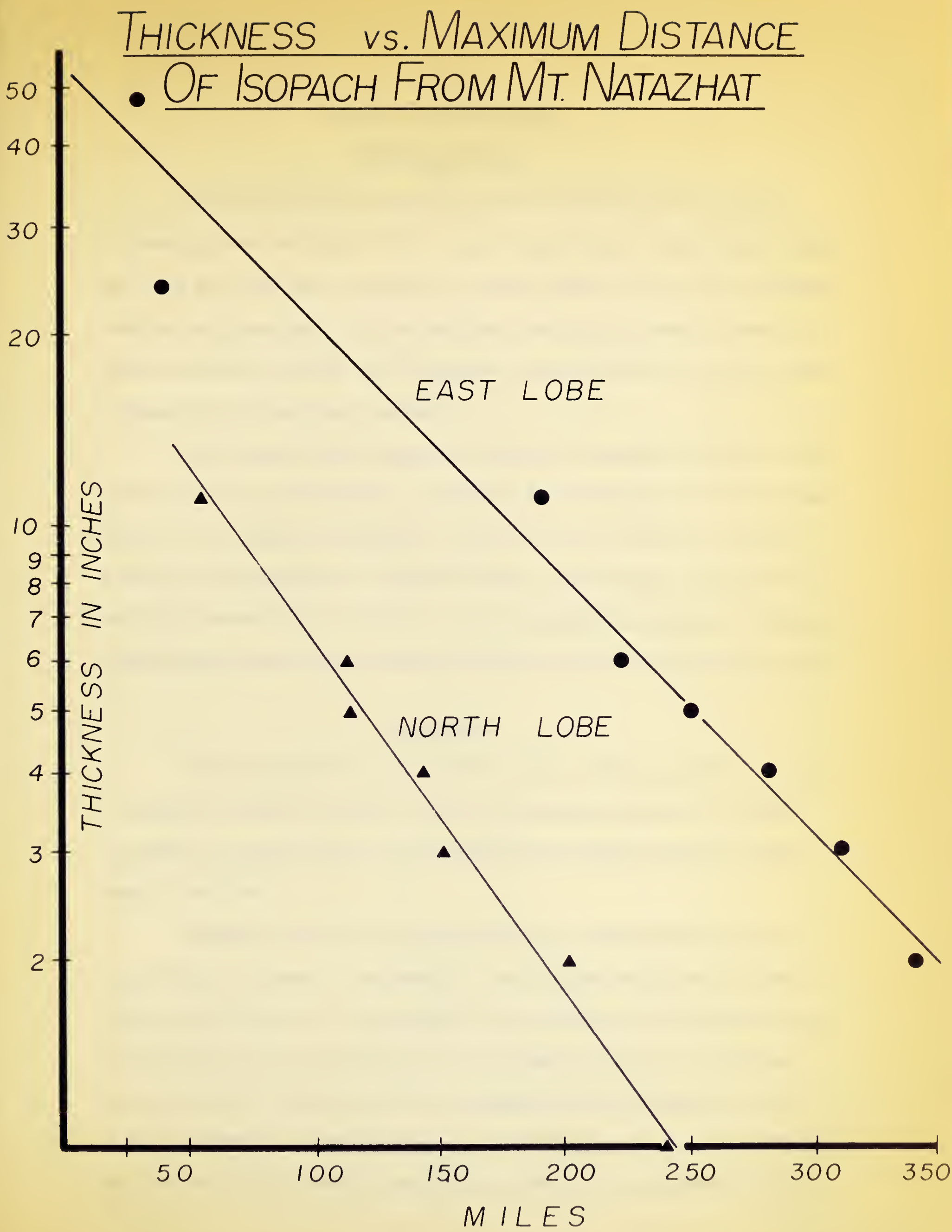

THICKNESS vs. MAXIMUM DISTANCE
OF ISOPACH FROM MT. NATAZHAT
50
40
30
20
10
9
8
7
6
5
4
3
2
THICKNESS IN INCHES
EAST LOBE
NORTH LOBE
50
100
150
200
250
300
350
MILES

FIGURE 2

# GRAIN SIZE ANALYSIS

## Size Terminology

As was mentioned in the introduction, the descriptive terms used in volcanology when referring to clastic ejecta have not been closely defined. Dust, ash, sand and lapilli are, or should be, distinguished by grain size but the boundaries are not agreed upon. Scoriae and pumice are distinguished by porosity but again the division is vague; ash is frequently used as a collective term but its use is inconsistent and can cause confusion.

In this dissertation the particulate material is treated as though it were from an ordinary clastic deposit. The Wentworth scale of grain size will be used along with the appropriate adjectives. Thus, dust is all the material less than 1/256 mm, ash lies between 1/256 and 1/16 mm, sand between 1/16 and 2 mm, and lapilli between 2 mm and 32 mm. It was considered unnecessary to distinguish between pumice and scoriae, therefore all frothy material will be called pumice.

## Procedures

The first step taken in the laboratory was to select a test sample and run it through the standard procedures used in size analysis to see how it behaved. The tephra is unconsolidated so it was hoped that the sample handling would be kept to a minimum.

Sample 1 was the first test sample chosen. After quartering down to approximately 150 grams it was placed on a set of sieves and run on a Ro-Tap machine for 20 minutes. It was hoped that this would give in one operation the sand distribution and a pan fraction ready for pipette analysis. Two problems were encountered: The first was that the organic material hindered the action of the sieves and it was feared that a poor distribution would result; the second was that the ash-sized material coated every surface and a considerable loss of

material resulted when trying to clean the screens. Because of this loss of material a pipette analysis was not run. Specific gravity separations of the sand-sized fraction by heavy liquids was attempted, but this procedure was also hindered by the presence of the organic material. Finally a determination of specific gravity of the ash fraction was made in order to calculate the withdrawal times for the pipette analyses on later samples.

Conclusions reached from test sample 1 were: (a) separation into sand and ash fractions would have to be done first by wet sieving, (b) organic material would have to be removed from the sand fraction before any analyses were made.

The next test made use of four samples from the same location; samples 9a, 9b, 9c, and 9d. It was felt that having four samples from the same location would provide some measure of control as well as indicating the variation likely to be found in samples collected from layers within the bed. Using the above refinements, the analyses were conducted with a minimum of difficulty encountered. After completion of these samples one change in procedure was implemented. In these samples the heavy liquid separations were made before dry sieving. This resulted in computational difficulties in arriving at the size distributions, so it was decided that for the remainder of the samples the distribution of the whole sample would be determined before gravity separations were made and their respective distributions determined.

Having received encouraging results from sample 9, five more samples were chosen for analysis. These samples were selected to determine the variation which would be encountered from different positions in the two lobes. Following the analysis of these five, thirteen more locations from the main lobe only were analysed in order to obtain good control of size and distribution variations. The secondary lobe to the north was not investigated further because the samples were of an inferior quality as compared to the samples in the main lobe, and it was felt that time was better spent on the main lobe where results were likely to be

more meaningful.

Altogether samples from 19 locations were size analysed by sieving and pipette analysis. The laboratory procedures are summarized in the flow chart (table 3).

## Laboratory Techniques

Most of the techniques used are fairly standard and described in such texts as "Manual of Sedimentary Petrography" by Krumbein and Pettijohn (1938) and "Petrology of Sedimentary Rocks" by Folk (1961). A few refinements, particularly in the pipette analyses were added to try to obtain maximum accuracy. The pipette analyses were done using a Shaw pipette rack fitted with a Lowy automatic pipette mounted on a moveable trolley on tracks. The Shaw pipette rack, with its adjustable scale, allows maximum accuracy in sampling depth. The Lowy pipette which is calibrated for 25 ml. at 20°C and operated by a vacuum system is a great improvement over ordinary pipettes. A full description with pictures of the apparatus is to be found in the catalogue of the American Scientific Company from whom it was purchased.

The screens used for both wet and dry sieving were the U.S. Standard sieve series, and the shaking was done on a Ro-Tap machine.

The specific gravity determinations were done in a quartz glass pycnometer using the procedures outlined by Ellsworth (1928) and Hutchinson (1923).

The specific gravity separations were done in glass separatory funnels using tetrabromoethane, (specific gravity 2.90), and a solution of tetrabromoethane and acetone with a specific gravity of 2.50.

The Blaine Fineness Tester used in the determinations of specific surface was the standard air permeability apparatus sold by the Precision Scientific Company, and the procedure followed was that outlined by the American Society for Testing Materials C 204-55 (1955).

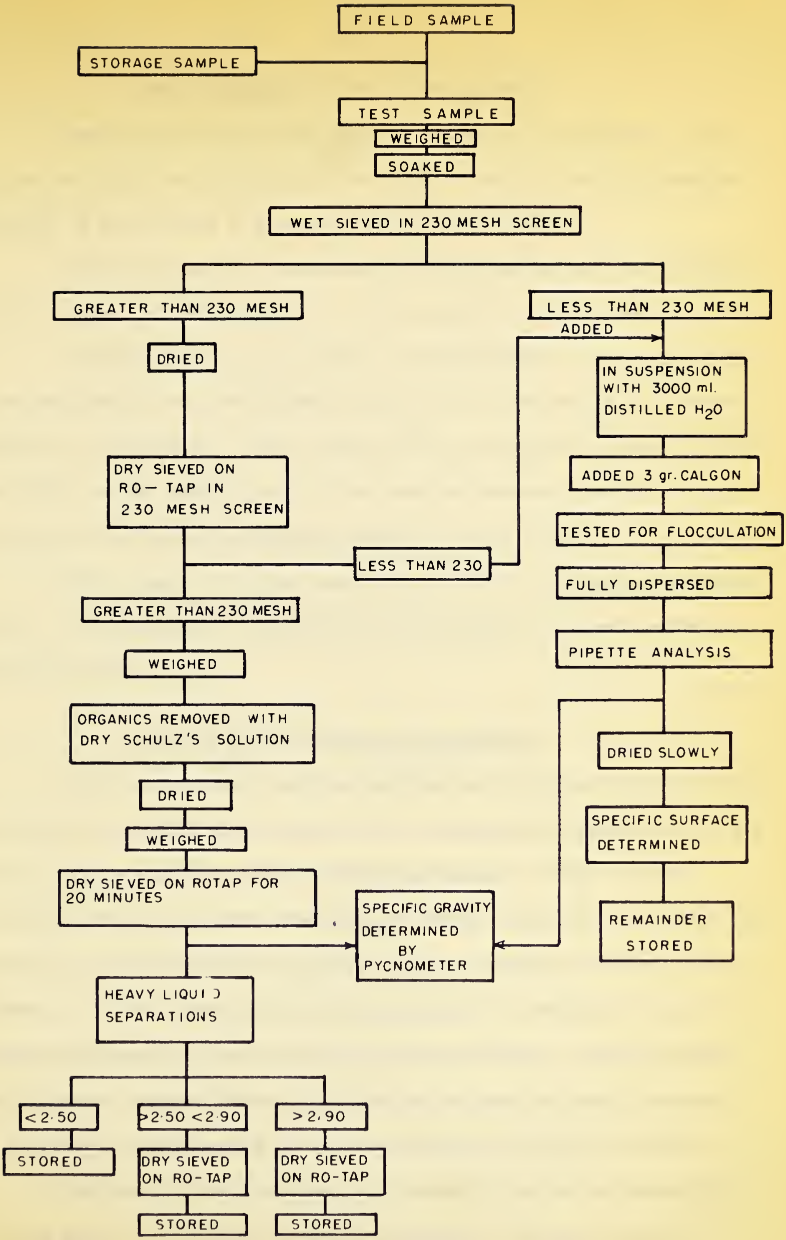



TABLE 3

Flow Chart showing Laboratory Procedures

## Results of Specific Gravity Determinations

Specific gravity determinations were needed for two purposes: (a) the calculation of the time of withdrawal charts (b) the calculations of the terminal velocities of the particles in determination of the vent position.

Three determinations were made on the ash fractions with the following results: sample 1 = 2.44, sample 25 = 2.38, sample 43 = 2.40, average = 2.41.

Two determinations were made on the sand fractions. For sample 32 the whole sand fraction was used, giving a result of 2.50. For sample 17 the model fraction only was used (i.e. -60 + 80 sieve fraction) which gave a result of 2.44. The slightly greater specific gravity of the sand fraction was expected as a concentration of the heavier mineral grains occurs in that fraction.

Earlier reports on the ash stated that up to 10% of the tephra floated on water. In the laboratory it was found that if the sample was properly wetted no grains would float.

## Results of Specific Surface Determinations

After the test samples had been analysed and the large proportion of ash-sized material noted, it was thought that very accurate size determinations of this material were going to be needed. Other than Waddell's (1936) empirical correction nothing was found in the geologic literature pertaining to a method for correcting values obtained from a pipette analysis. A paper by Hofmann (1956), however, in which he proposed obtaining an angularity coefficient for grains by measuring the specific surface of the grains and comparing it to the calculated specific surface obtained from the size distribution, gave the theory necessary for providing a correction to grain size data obtained from pipette analyses.

The theory is that from measuring the specific surface and determining the mean grain size this value can then be compared to the mean grain size obtained by pipette analyses and a correction factor applied. This procedure

hinges on the assumption that the mean grain sizes determined from measurements of specific surface are very accurate.

The apparatus chosen for this work was the Blaine Fineness Tester because of its simplicity and availability. Very accurate work on specific surface determinations is generally done using gas absorption techniques, but all of these require an elaborate apparatus, and it was hoped that this would not be needed. The four test samples from location 9 were run. The results were discouraging, as the mean grain sizes calculated were in the order of three times as great as the modal values obtained by pipette analysis, which were taken to be close to the mean values. It was therefore decided to leave this project for the time being.

After more samples were size analysed, it was realized that it was not as important as originally thought to have accurate absolute grain sizes in the ash fraction, and that relative values for comparison purposes would probably be adequate. As a result specific surface determinations were not resumed.

The technique is still thought to be useful however, and as it does not seem to be in the geologic literature up to the present time, it was felt that it deserved mentioning. If a more refined technique was used for determining specific surface it is very likely that positive results could be obtained.

## Data Processing

There were 49 grain size analyses in all from 19 sample locations. The list of these analyses is given in table 7. In order to speed the computations on these analyses a computer program was written that would calculate sample weight, cumulative weight, individual percent and cumulative percent. Details of the computer program are discussed in Appendix A. From the output of the computer program, cumulative curves were plotted and from these were calculated the following statistical parameters: mode, mean, standard deviation, skewness and kurtosis. Plots of these parameters against distance were made and are shown in figures 5, 6 and 7.

To demonstrate the methods and show the formulas used in the calculation of statistical parameters, an example is worked out in Appendix B.

## Discussion of Results of Grain Size Analysis

### Cumulative Curves

The cumulative curves for all 49 runs were plotted on probability paper (cululative percent vs. phi*). In examining the example curves shown in figure 3 it will be noticed that the curves have not been drawn through all the plotted points. Ordinarily this "smoothing" is dangerous, as it may hide certain characteristics. However, in this case it is felt justified as the points which are missed are those which are back-distributed by the computer program. As it is unlikely that the material on any one screen is equally distributed about the midpoint of the interval represented by the screen, these points were only used as guides and not necessarily rigidly followed. The only exception to this is the point plotted for the 170 mesh screen (3.5 phi). After the analyses were complete it was noticed that this value was always low. Microscopic examination of the screen showed several structural defects, therefore the curves have been drawn as though this screen was not included in the analysis.

There are three types of curves resulting from the grain size analysis. For easy reference these will be called type 1, type 11 and type 111 curves. Type 1 curves represent samples in which both sand and ash were analysed; type 11 curves represent samples in which only sand was analysed; and type 111 curves represent the distributions of the specific gravity separates of the sand. All three of these types have their own characteristics and within each type the curves are very similar.

*Phi is defined as the negative logarithim to the base 2 of the size in millimeters; i.e.

$$d = 2^{-\phi}, \text{ where } d = \text{dia. in mm}$$

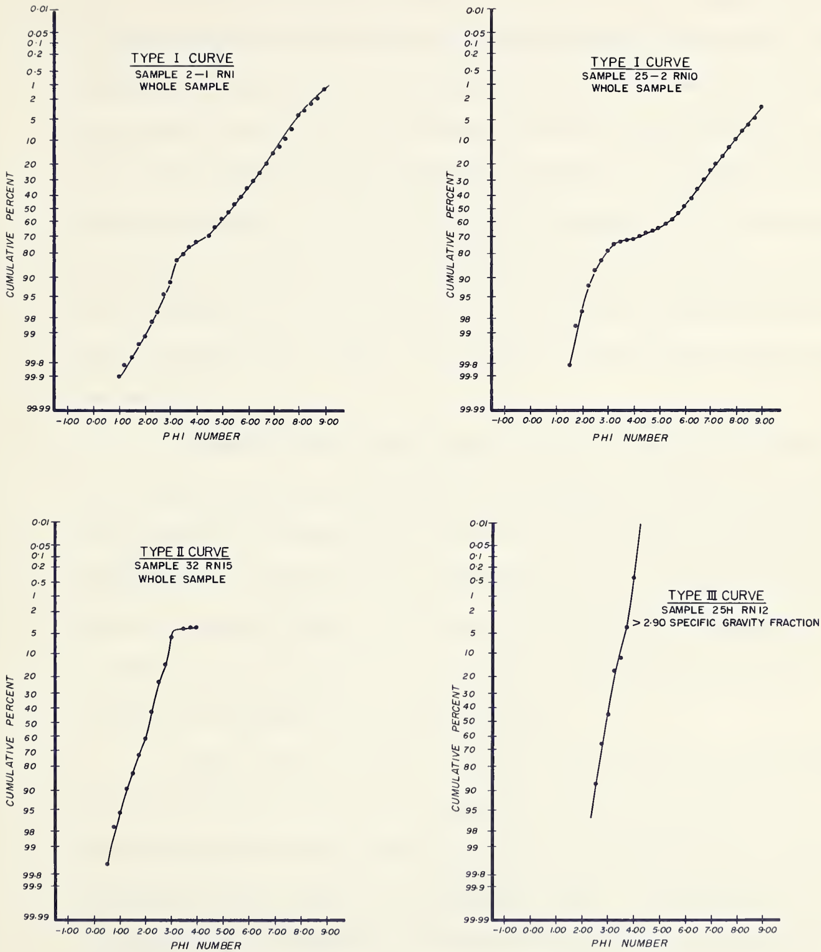



FIGURE 3. Type I, II and III Cumulative Curves.

Type 1 curves are composed of two parts which appear to be two separate distributions. The first part, which generally shows an excess of material near the mode, ranges down to approximately 4-phi. The second part, ranging from 4-phi to 9-phi, usually is almost normal with flattening towards the finest sizes. The most obvious feature of these curves is the lack of material between 3.5-phi and 5-phi in most cases. At first it was feared that because this paucity fell in the region of the change of analysing technique, that there was a systematic error in the pipette analyses. It is true that this would account for some of the discrepancy as there was no correction made for grain shape in the pipette analyses, but there is still the definite paucity of material in the last few sieve intervals which are shown in Appendix D to contain at least 85% of the total sample in their respective intervals.

The evidence that strongly suggests that these two parts of the curves are actually two different distributions is the difference in slope of the two parts. This is the usual interpretation of this phenomenon and is one of the reasons why a probability scale is used rather than an arithmetic scale. It appears, although control is somewhat lacking, that the spread between these two distributions increases towards the origin of the tephra-fall. The significance of these two distributions is discussed in the section on modes.

Type 11 curves are usually very close to being normal, not showing the bulge around the mode that type 1 curves show. As the type 11 curves are representative of the samples closer to the origin it would appear that the bulge appears as the distance from the origin becomes larger. The significance of this is not completely understood but it could be due to insufficient sieving time in the finer samples. These curves tend to flatten sharply at the fine end.

Type 111 curves are the most consistent of the three. They are always near-perfect normal distributions. However, the modal determinations show that these curves may be unreliable as it is feared that not enough sample was used to give valid results.

## Modes

The modal grain size for each sample was determined from its cumulative curve as described by Folk (1961). In the whole samples for which the size distribution of the ash fraction was determined, two modes were calculated, one in the sand fraction and one in the ash fraction.

Whole Samples:

The modes for the sand fractions were plotted on a map in order to best appreciate their relationship to each other and to the deposit as a whole. As expected, the values become smaller as the distance from the origin increases. It was also seen that the values grow smaller as the distance perpendicular to the axis increases. This latter result is not expected on a theoretical basis. To elucidate this fact, the theory for tephra fall-out will be briefly explained (Knox and Short, 1963).

The particles which are taken into the initial cloud are thoroughly mixed throughout its volume. However, during the few minutes that the cloud is ascending its rate of rise decreases, and more and more of the larger particles fall out. Hence, the result is an altitude distribution of particle sizes that becomes more marked the higher the cloud rises from the vent. It is important to realize, however, that particles begin to fall out shortly after the explosion, much before the cloud reaches maximum altitude.

The dynamic fall-out modal used by meteorologists to predict fall-out from nuclear explosions, and which has now been applied to volcanic explosions, represents the particle size distribution of fall-out in time and space by means of the trajectories of a number of theoretical discs, each with given particle size limits. These discs make up the volcanic cloud which can be visualized as being a cylinder composed of a homogeneous mixture of particle sizes. In this cloud there are discs for every particle size class being considered, and for any one

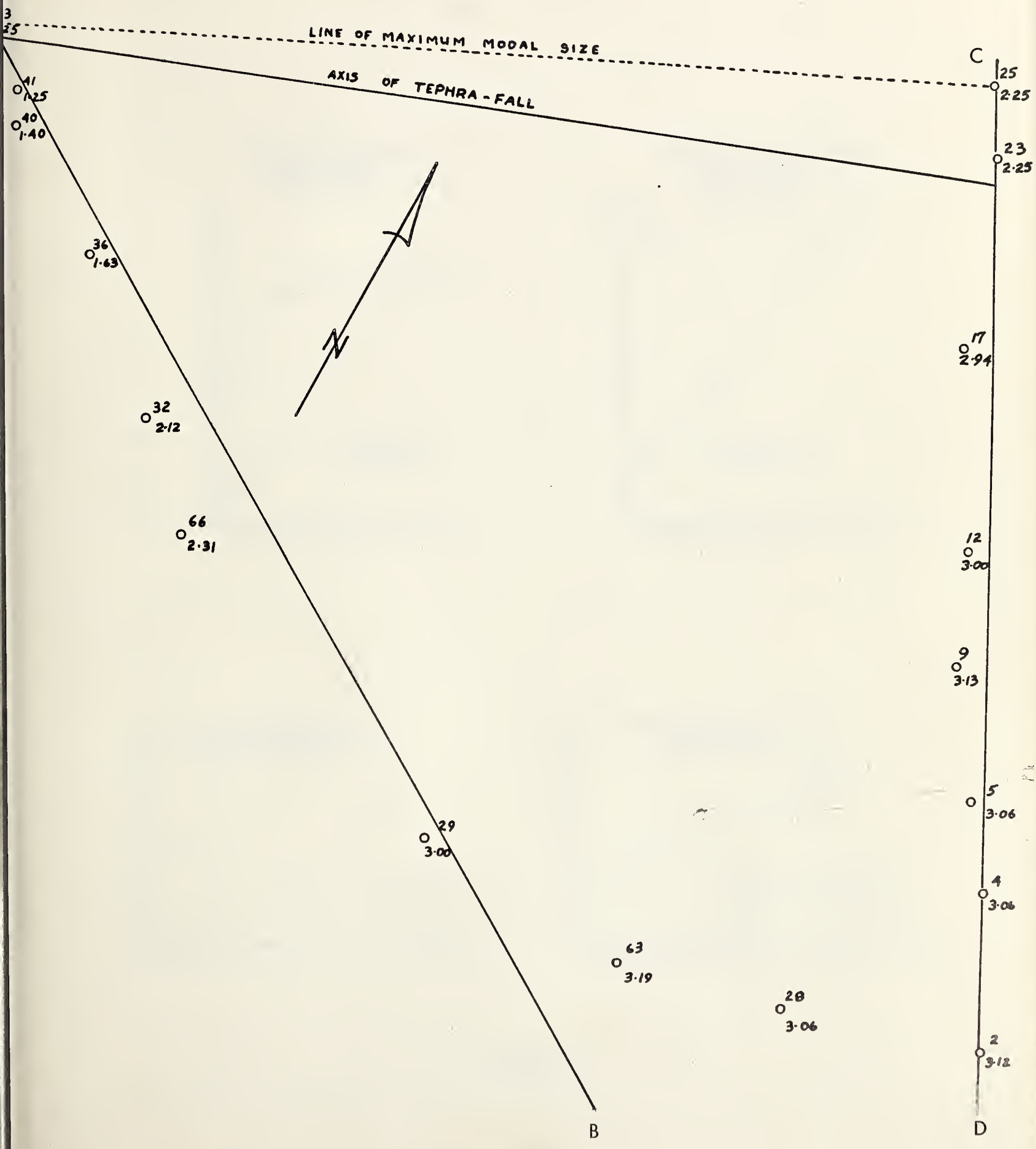
particle size class there are an infinite number of discs composed of particles in this size class between the top and the bottom of the cloud. The trajectory of the centre of each disc is found from the particle size, time-altitude history, and wind velocity data. In order to calculate the motion of a given disc, the particle size at the mid-point of the size class is used. A particle of this size is assumed to be at the centre of the disc. The greater the time history of any disc, the greater the radius of the disc becomes because of horizontal eddy diffusion. It is this expansion which causes the lobe of deposition to become wider with distance. It is from this pattern width of the lobe that we can calculate the height of the stabilized cloud using formulas derived from the study of nuclear explosions.

Therefore, when studying a tephra fall it is required to reverse the theoretical process. That is, the position of a certain particle size is known and it is required to find the position of its disc at time-altitude zero.

From this model it would be expected that each class would occupy a band in the deposit with the mode of the class in the middle of its band. The width of the band would be controlled by the vertical dimension of the cloud and the wind velocity. The mode for any given grain-size class should form a line perpendicular to the axis of the fall.

As was pointed out, this tephra fall does not show uniformity of modal size in a direction perpendicular to the axis. In order to obtain a better picture of the distribution, the samples were divided up into two traverses as shown in figure 4. The modal phi values were plotted against distance along these traverses (figure 5). The graph shows what may be a straight line relationship down to approximately 3-phi and then a break to a much smaller slope. If so, it has not been determined what the cause of this break may be. Thorarinsson (1954) in his study of the tephra-fall from Hekla found a similar result but he too could offer no explanation.

FIGURE 4. Sample Locations of Traverses AB and CD on Main Lobe.



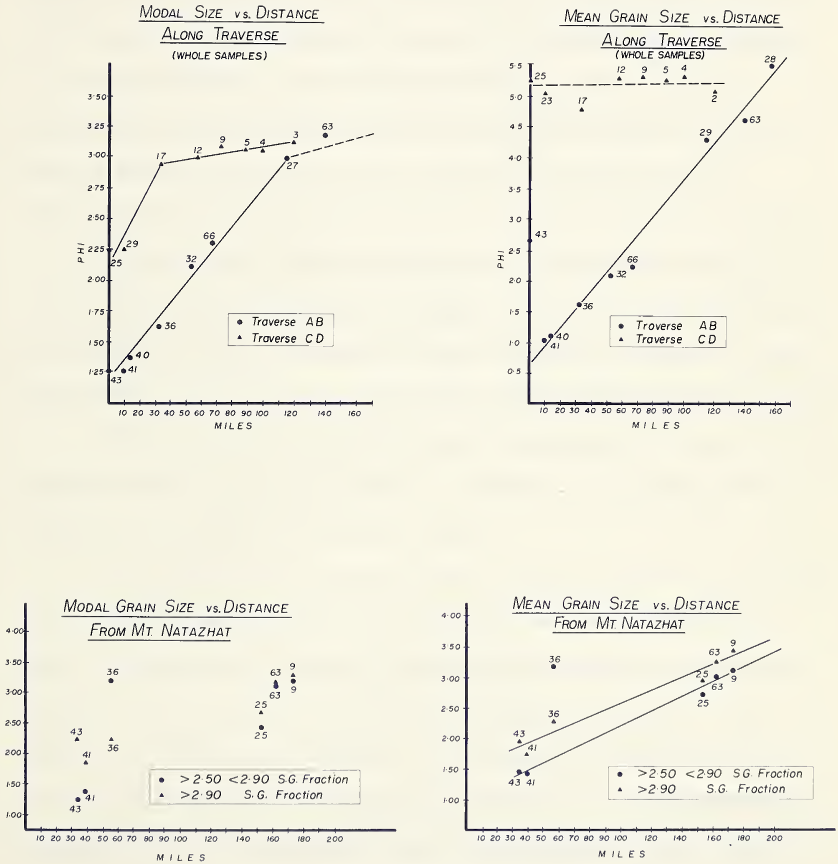

MODAL SIZE vs. DISTANCE
ALONG TRAVERSE
(WHOLE SAMPLES)
PHI
MILES
• Traverse AB
▴ Traverse CD
MEAN GRAIN SIZE vs. DISTANCE
ALONG TRAVERSE
(WHOLE SAMPLES)
PHI
MILES
• Traverse AB
▴ Traverse CD
MODAL GRAIN SIZE vs. DISTANCE
FROM MT. NATAZHAT
MILES
• >2·50 <2·90 S.G. Fraction
▴ >2·90 S.G. Fraction
MEAN GRAIN SIZE vs. DISTANCE
FROM MT. NATAZHAT
MILES
• >2·50 <2·90 S.G. Fraction
▴ >2·90 S.G. Fraction

FIGURE 5.

If the phi values for size along the two traverses in the south half of the lobe are plotted on a single stereographic projection, they are found to fall on a single planar surface dipping toward the fall axis. Therefore, plotting phi on a vertical scale above the map for the whole lobe should produce two planar surfaces dipping toward the lobe axis, the line of intersection occurring directly above this axis and plunging in the direction of the source, i.e. toward the west. Contours of equal phi are therefore chevron-shaped pointing to the east. It must be remembered that the phi scale is a negative logarithm of the grain size in millimeters; therefore, the grain-size surface if plotted in millimeters would be exponentially curved and slope away from the axis as well as away from the source.

This distribution can be explained only by visualizing the theoretical discs as being shaped as though they were draped over a similar exponential surface about the axis of the fall. The reason for such a draping is not apparent at present. Observations made on an erupting volcano might aid in understanding the mechanism.

Thorarinsson in his study did not have a traverse across the lobe so that no comparison with his tephra-fall is possible. Therefore it is not known whether or not the distribution noted in this study is unusual.

The modal values for the ash fraction in the whole samples were examined next, and these posed a problem. From the theoretical modal, particles of ash size in such quantity as to produce a mode should not be present in the locations examined. If the cloud when it stabilized at maximum height became strongly graded with the fine material at the top, and the lower level winds were faster than the high level winds, a bimodal deposit would result. It is difficult to assess this possibility without knowing what degree of wind gradient would be required to give the resultant deposit. Not having enough control along the axis for the modal values in the ash, it was not possible to calculate a wind velocity to compare with that calculated from the sand fraction.

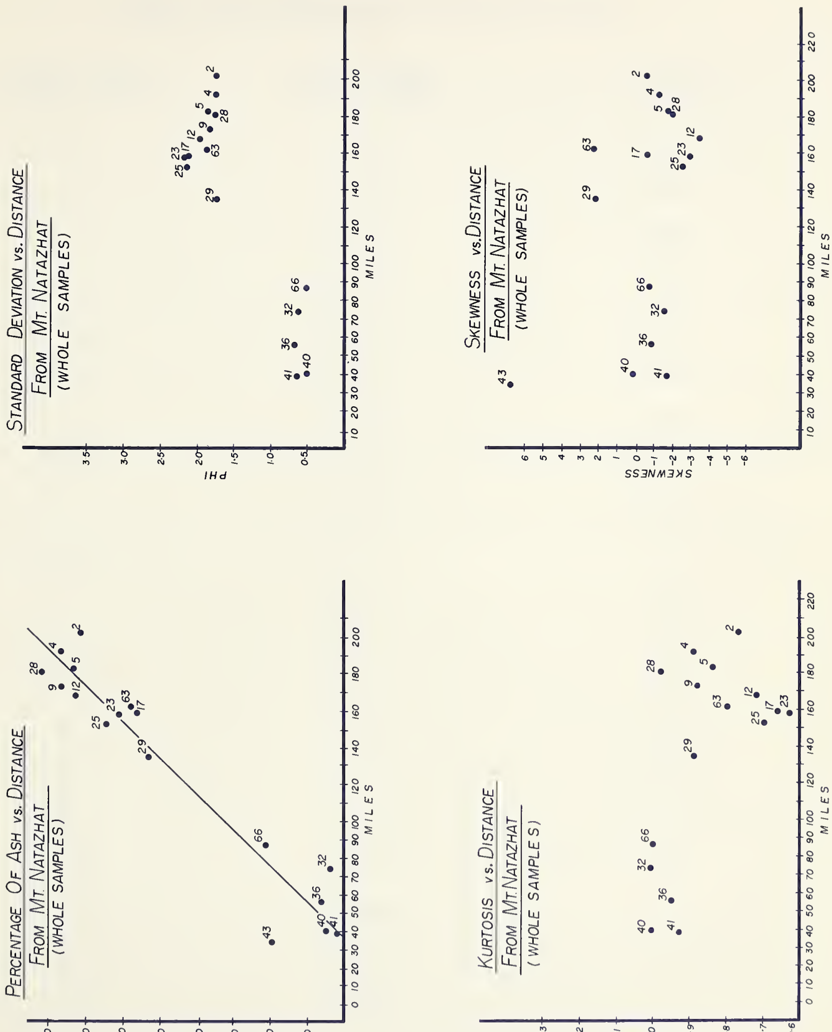
In view of this, a possible alternate explanation will be put forward from the information that is available. In addition to the determination of the modes, the percentage of ash in each sample was plotted against the distance from Mt. Natazhat, a convenient reference point lying on the axis of the main lobe and previously thought of as being the location of the vent. Figure 6 shows that there is probably a linear relationship between percentage of ash and distance.

The modal size values for the ash, however, (table 4) show very little variation. This is due in part to the fact that most of these samples are fairly close together in relation to their distance from the origin. The three samples (neglecting sample 43) that are closest to the origin do show a marked coarsening of the ash fraction to almost sand size. This would seem to indicate that whatever process was operating, it led to some differentiation.

Another fact to be considered is that sample 25, lying on the axis with a sand mode of 2.25 phi, has a percentage of ash of 69.88 and a mode for the ash of 6.35 phi. This can be compared to sample 5 which has a mode for the sand of 3.06 phi, a percentage of ash of 73.07, and a mode for the ash of 6.25 phi. The modes for the ash are very similar but the modes for the sand are considerably different.

The variations of percentage of ash and modal size of the ash with distance from the source indicate that a mechanical breakdown is not the cause of the pecular distribution, nor is it controlled in any way by the thickness of the bed.

Thorarinsson (1954) did not find anything comparable to this in his grain size analysis. Of the samples he analysed the greatest amount of ash in any one sample was 25%, but this sample had a modal value of approximately 4.0 phi. That is, the mode lay on the screen that defines the division between sand and ash. Most of his samples had less than 10% ash in them. Therefore, it



Percentage Of Ash vs. Distance
From Mt. Natazhat
(Whole Samples)
Weight Percent
Miles
Standard Deviation vs. Distance
From Mt. Natazhat
(Whole Samples)
Phi
Miles
Kurtosis vs. Distance
From Mt. Natazhat
(Whole Samples)
Kurtosis
Miles
Skewness vs. Distance
From Mt. Natazhat
(Whole Samples)
Skewness
Miles


FIGURE 6.

TABLE 4

MODES AND PERCENTAGES OF ASH FRACTION

| Sample Number | Mode of Ash Fraction (PHI) | | Percentage of Ash |
|---|---|---|---|
| 2 | 5.90 | | 71.22 |
| 4 | 5.90 | | 76.47 |
| 5 | 6.25 | | 73.07 |
| 12 | 6.25 | | 72.46 |
| 17 | 6.50 | | 56.00 |
| 23 | 6.50 | | 60.88 |
| 25 | 6.37 | | 69.35 |
| 28 | 5.50 | | 81.70 |
| 29 | 4.30 | | 52.70 |
| 32 | *ND. | | 3.79 |
| 36 | ND. | | 6.27 |
| 40 | ND. | | 5.00 |
| 41 | ND. | | 2.00 |
| 43 | 7.25 | | 19.74 |
| 63 | 4.3 | | 57.47 |
| 66 | ND. | | 21.41 |
| 9A | 6.50 | Av. | 76.22 |
| 9B | 6.00 | | |
| 9C | 6.37 | | |
| 9D | 6.25 | | |

* Not determined.

it can be concluded that whatever process brought the ash down in the White River fall may not always be operative.

The above information led to the conclusion that the ash might have been brought down by water droplets. This seems quite plausible when it is remembered that water vapour is the most important constituent of volcanic gases and can compose over 99% of the total volume. When this water vapour is shot up to approximately 70,000 feet where the temperature ranges from -72°F in January to -45°F in July (Handbook of Geophysics) rapid cooling will occur and the water vapour will condense. In this process of condensing the ash particles may serve as nucleation points, become coated with water, collide with other coated particles and soon may form sizeable drops loaded with ash particles. With continued cooling they may turn into ice or snow. In any case, this will effectively increase the grain size of the ash particles and they will fall with a greater terminal velocity than expected.

As there will be an interval of time necessary to allow for sufficient cooling, there would be little or no ash material deposited in this manner close to the origin. It can also be postulated that the condensation occurs slowly at first then increases as the main mass of the cloud cools. This could partially explain the linear increase in grain size closer to the origin; presumably water droplets with larger particles in them had a greater specific gravity and hence a greater terminal velocity.

When considering this process it is attractive to think of snow falling at the same time as the tephra was deposited. This would explain to a considerable degree the excellent preservation of the tephra. It would give the tephra a chance to become compact before being attacked by wind and other erosional agents. It would also explain why the ash is fairly well preserved on steep slopes.

A proposal that the tephra fell during the winter months would be

substantiated by the present day wind patterns in the area. January winds between 20,000 feet and 70,000 feet come from the west having means between 250° and 290° depending on the elevation. July winds swing around to the north varying between 270° and 90° depending on elevation (Handbook of Geophysics).

The modal values for the two samples analysed on the northern lobe show that there was either not as strong a wind blowing, or the explosion was not as powerful when this deposit was erupted. This conclusion is substantiated by the lesser extent of the deposit.

Specific Gravity Separates:

The plots of grain size versus distance for the modal values of the two specific gravity fractions of the sand fraction are rather disappointing (figure 5). They indicate generally a finer mode with increasing specific gravity, but the values tend to be somewhat erratic and sample 36 shows a reverse situation. These results are attributed to the analysis of too small a sample.

It was originally hoped that it could be shown that these separations would provide a basis for analysing ancient tephra-falls in which the glassy component has been badly altered. Even though it could not be shown conclusively in this study that this is possible, it is felt that the results are somewhat encouraging.

Means

The graphic mean which was determined for these samples corresponds very closely to the mean which is calculated by moments and is the best measure for determining overall grain size from cumulative curves.

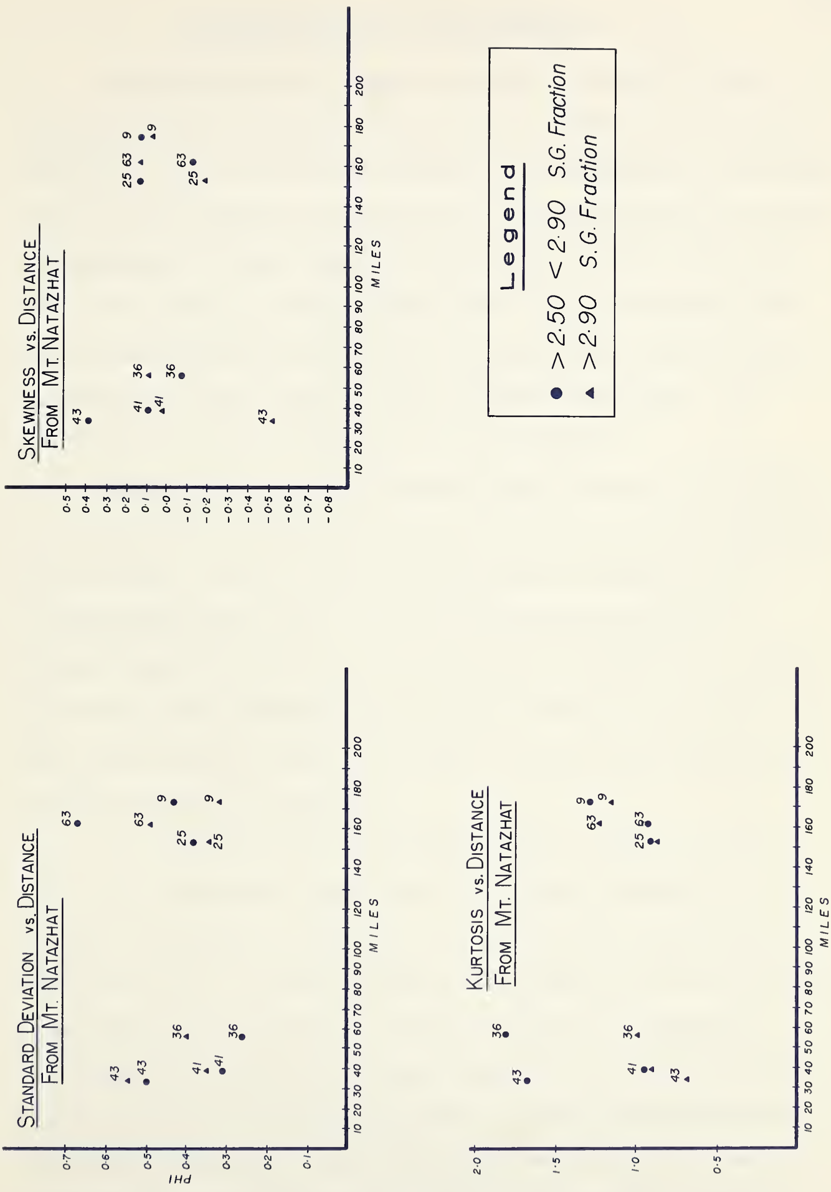
The means were plotted against the distance along traverses AB and CD (figure 5). Both traverses show linear trends somewhat different from those found for the modes. One interesting feature of these plots is that there is no break in the line around the 3-phi value. It is probable that this feature is smothered by the increasing percentage of ash by the time a mean value of 3-phi is reached.

The mean grain sizes for the specific gravity separations show a more regular distribution than do the modes. Sample 36 is still reversed and stands alone, but the rest of the points lie close to a straight line drawn through them.

The means were not particularly useful for interpretation in this study but should prove interesting for comparison purposes with similar studies of other tephra-falls. They do, however, give an indication that variations in the specific gravity fractions are similar to variations present in the whole samples.

Standard Deviation, Kurtosis and Skewness

All three of these parameters were calculated for every run and plotted against distance from Mt. Natazhat (figures 6 and 7). The results of these plots do not appear to lend themselves to any useful interpretation at the present, but they are included to serve as a basis for comparison in further studies.



Skewness vs. Distance From Mt. Natazhat
Standard Deviation vs. Distance From Mt. Natazhat
Kurtosis vs. Distance From Mt. Natazhat
PHI
MILES
Legend
● >2.50 <2.90 S.G. Fraction
▲ >2.90 S.G. Fraction


FIGURE 7.

## DETERMINATION OF VENT LOCATION

Recent advances in the study of dynamic fallout modals for nuclear explosions has led to a method of analysis of tephra-falls which has not been possible previous to 1963. The similarity of plinian volcanic explosions to near-surface cratering nuclear explosions led to the application of the most recent fallout modal to interpretation of the tephra-fall from Hekla by Knox and Short, (1963). The theory that is necessary to perform the calculations is given in this paper as well as the example calculation for Hekla. For the complete theory and derivation of the equations the reader is referred to their paper and its bibliography. The calculations for the figures that follow are given in Appendix C.

The only information that is required for these calculations is the outline of the tephra-fall, the tephra-fall axis, the size distribution and the density of the modal particles. The theory is only applicable however on lobes which are elongated sufficiently to allow an accurate determination of the axis and a sufficient spread of particle sizes. There are also grain size limits for best results, which Knox and Short estimate to be between 8 and 1/64 mm (-3phi to 6phi). Other limiting factors are given in their paper, but as they refer to rather special cases they need not be mentioned here.

The White River Ash is nearly ideal for this type of study, the eastern lobe being over 450 miles in length and having undergone considerable study so that an accurate outline of the deposit in conjunction with the isopachs make it easy to draw an axis. The breadth of the lobe, an integral part of the calculation, is measurable over a long distance, which means that had more samples been taken along the axis many determinations of vent location could have been made and then averaged. It is unfortunate that only two of the available samples came from the axis of the deposit. This is the minimum number of samples required to perform this calculation. Fortunately, control around these samples was such

that it is fairly certain that the modal values used in them are correct.

Before discussing the result of the calculation of vent position of the White River Ash, a brief summary of the history of proposed vent locations may be informative. Most of the individuals who made mention of the tephra in their reports also speculated on the position of the volcano. Dawson (1889) who didn't go as far west as the Wrangell mountains reported however that indians speak of a "burning mountain" near the head waters of the White River. It was not certain however, whether or not the mountain referred to was Mt. Wrangell, a known volcano. Hayes (1892) suggested that the source of the ash was in the mountains near the source of the Klutlan Glacier. Brooks (1900) agreed with this and reported that blocks of pumice up to six inches in diameter were being brought down by the glacier. Capps in his comprehensive report stated that he believed that Mt. Natazhat, or part of it, was the volcano. This conclusion was based on his belief that the tephra was up to 300 feet thick on the lower slopes of Mt. Natazhat (a belief that was based upon observation from a distance), and on a report by a surveyor who said that he had seen a small crater in a glacial cirque 4 miles N.N.E. of Mt. Natazhat. This reported crater has not been reported by anyone else. Capps was going to investigate, but an unseasonal snowfall and shortage of provisions halted the expedition. Bostock (1952), not having first hand information on the area, studied aerial photographs and reported that although no crater was visible the distribution indicated that Capps could be correct. Berger (1960) however, refuted the thicknesses reported by Capps. His personal observations were that the thickness of tephra in the Upper White River Basin have an average range from 1 foot to 7 feet with a maximum thickness of approximately 10 feet. Berger's information destroys some of the best evidence for stating that Mt. Natzhat is the volcano. As far as the reported crater is concerned, it is doubtful that the crater produced by such a

tremendous explosion as was responsible for this deposit would be described as "small".

The calculation of the position of the vent from the size distribution (see Appendix C places the volcano about 40 miles southwest of Mt. Natazhat on the southwest side of Mt. Bona in the area occupied by the smaller Pyramid and Andrus Peaks. This places the volcano outside the present isopachs, but this is not at the moment a serious shortcoming as the area surrounding Mt. Bona has never been closely examined. The whole region is buried under a permanent snow cap and is heavily glaciated.

It is not likely that either Pyramid Pk. or Andrus Pk. are individual volcanoes; they are merely shoulders of Mt. Bona. Mt. Bona itself however, may be a volcano. Reaching 16,421 feet it is the largest mountain in the immediate vicinity and exhibits a very strong radial distribution of glaciers on its slopes. This can be coupled with the fact that granular intrusives outcrop at the base of the mountain in the White River valley.

In conclusion, it seems logical to suggest that Mt. Bona, is the source of the White River Ash. If the axis of the two lobes are extended they intersect directly on Mt. Bona. The peak of Mt. Bona lies only 25 miles to the east of where the calculated vent location lies. This distance would seem to be a reasonable error for this calculation. It is unfortunate that there was no opportunity to study aerial photographs of the region but coverage for this area was not immediately available. It can be hoped that a careful look at these photographs will disclose a crater.

Calculation of the vent position includes a calculation of the energy of the explosion and the maximum and mean heights of the cloud. A calculated energy of 33.7 kilotons of TNT, and maximum and mean cloud heights of 21.6 and 16.8 kilometers appear to be of the right order of magnitude, although little information on energy of volcanic explosions is available. This additional inform-

ation is therefore of considerable interest and a further motive for studies of this type.

## SUMMARY

The investigation of the White River Ash revealed a number of qualitative and quantitative aspects of a tephra fall which are of interest:

1. When the logarithim of the thickness of the tephra bed is plotted against distance from the vent, or some reference point on the axis of the fall as near as possible to the vent, a straight line function results.

2. The tephra fall appears to be composed of two grain size distributions which must be explained by the method of deposition. Two alternative hypotheses were put forward to explain this phenomenon:

   (a) a strongly graded cloud with the low level winds having more velocity than the upper level winds.

   (b) the fine fraction brought down pre-maturely by water droplets or snow.

3. The modal grain size distribution of the main lobe is somewhat different than is predicted by the theoretical dynamic fall-out modal in that the size decreases in a regular manner both along and perpendicular to the lobe axis.

4. It was indicated that it may be possible to use mineral separates for the study of ancient tephra falls which have undergone weathering.

5. Various statistical parameters calculated from the data determined by size analysis were plotted against distance, and several consistencies were observed and explained.

6. A new method for calculating the position of the vent which erupted the tephra fall was used and the results suggested that Mt. Bona was likely to be the vent rather than the previously reported Mt. Natazhat. From the calculations the following additional parameters which may be useful in the comparison of other tephra falls were determined:

| | | |
|---|---|---|
| Energy of explosion | = | 33.7 kilotons of TNT |
| Mean height of cloud | = | 16.8 km. |
| Maximum height of cloud | = | 21.6 km. |

## CONCLUDING REMARKS

It is felt that there is much more investigation to be done on problems of this nature, and positive results that were obtained in this study should provide encouragement for continued study. Further studies should be made of recent well preserved beds until more data has been massed. Eventually however, this data should be applicable to the study of ancient tephra falls for the determination of the location of ancient volcanic belts and the definition of ancient wind patterns. These results will be very useful to stratigraphers in basin analysis.

From the results of this study a few helpful suggestions can be made for future reference. Sampling should be as extensive as possible but it is very important to obtain closely spaced samples from the axis. It is also very important to have several traverses across the lobe with closely spaced samples, as these will define the lateral variation.

In grain size analyses the smallest sieve intervals should be used; this applies as well to the sub-sieve range where pipette analysis will probably be done, for it is extremely important to obtain accurate modes. It is also important to have enough sample from each location to allow for an extraction of large samples of various specific gravity fractions. Particular attention should be given to these separates as it is likely that in working with a smaller range of specific gravity more accurate determinations of vent locations can be made, and study of these mineral separates will open the way for study of ancient tephra deposits.

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# APPENDIX A

## Computer Program

PROGRAM 913109 Grain Size Analysis

Statement of problem: It is required to calculate the sample weight, cumulative sample weight, individual percent and cumulative percent given the sample plus container weight and the container weight. For the calculation of these measures from the data from the pipette analysis, the dispersion weight and multiplication factor are also given. The method of calculation is that given by Folk (1961) and by Krumbein and Pettijohn (1938).

Programing details: The program was written in Fortran 11 and compiled with a floating-point word length of 8 characters and a fixed-point word length of 4 characters.

Equipment:

IBM 1620 Data Processing System with

(i) 1622 Card Read Punch

(ii) 1623 Core Store Unit with one 40K nodule

Limitations on data and Parameter:

The number of phi intervals must not be more than 12.

Input: (a) Parameter cards

| | |
|---|---|
| Col. 1 | Blank |
| Cols. 2 - 20 | Run identification |
| Cols. 31 - 35 | Starting phi number (with sign if negative) |
| Cols. 41 - 45 | Ending phi number |
| Cols. 51 - 55 | Dispersant weight |
| Cols. 61 - 65 | Multiplication factor |
| Cols. 76 - 78 | Run number (or data identification) |

(b) Data card

| | |
|---|---|
| Col. 1 | Blank |

| | | | |
|---|---|---|---|
| Cols. | 2 - 6 | phi number (with sign if negative) | |
| Cols. | 8 | code | o - sieve<br>1 - pipette |
| Cols. | 11 - 18 | Sample plus container weight | |
| Cols. | 21 - 28 | Container weight | |

All the data cards have the same format. The first pipette reading must be given a unique phi number and cannot be a duplicate of any sieve reading phi number. In this thesis all the initial pipette readings were given the number 4.25 phi.

The data cards may be in any order within a particular set with the exception that the card with the ending phi number reading must be the last card of the data set.

Order of cards:

(a) Program 913109

(b) Parameter card

(c) Data cards

repeat (b) and (c) for subsequent runs

Note that each set of data except the first must be preceded by the following two cards:

..I

..BRANCHb0040R

Output: (a) Data cards

| | | | |
|---|---|---|---|
| Col. | 1 | Blank | |
| Cols. | 2 - 6 | phi number (with sign if negative) | |
| Cols. | 8 | code | o - sieve<br>1 - pipette<br>2 - distributed |
| Cols. | 11 - 18 | Sample plus container weight | |

Cols. 21 - 28 Container weight

Cols. 31 - 38 Sample weight

Cols. 41 - 48 Cumulative sample weight

Cols. 51 - 57 Percent weight

Cols. 61 - 67 Cumulative percent weight

Cols. 76 - 78 Data identification (from parameter card)

(b) Total card

Col. 1 Blank

Cols. 2 - 8 Total sample weight

Cols. 11 - 18 Total pipette sample weight

Cols. 76 - 78 Data identification (from Parameter Card)

Notice in the data that the initial pipette reading of phi 4.25 gives no sample weight, but the weight calculated is in the total card as pipette sample weight.

Test Data and results: The test data is from sample number 4. All the values computed corresponded with those calculated using a desk calculator.

Programmer: Mr. Richard Newson.

```
..I 913109              GRAIN SIZE ANALYSIS        L.HANSON
..LOAD FORTRAN EXECUTE DUMP
    1 FORMAT(A4,A4,A4,A4,A4,10X,F5.2,F10.2,F10.3,5X,I5,9X,A4,A2)
    2 FORMAT(F6.2,I2,F10.4,F10.4,52X)
    3 FORMAT(/F6.2,I2,4F12.4,2F10.2,6X,A4,A2)
    4 FORMAT(///F10.2,F10.2,54X,A4,A2)
    5 FORMAT(/1X,4H PHI,1X,2H C,5X,4H S+C,7X,5H CONT,8X,4H SWT,8X,4H CWT
     1,8X,4H IPC,6X,4H CPC)
      DIMENSION  PHINO(49),IPHI(49),SCWT(49),CWT(49),SWT(49),ASWT(49),PS
     1WT(49),APSWT(49)
  200 READ 1,A1,A2,A3,A4,A5,FIS,FIE,DISP,MULT,DATAID
      PUNCH1,A1,A2,A3,A4,A5,FIS,FIE,DISP,MULT,DATAID
      PUNCH5
      IFIS= ABSF(FIS*4.+5.)
      IFIE= ABSF(FIE*4.+5.)
      XMULT=MULT
      TOTWT=0.
      PIPWT=0.
      PWT=0.
      TPWT=0.
      TSWT=0.
      TPHI=-1.25
      DO 10 N = 1,49
      PHINO(N) = TPHI + 0.25
      TPHI = PHINO(N)
      IPHI(N) = 2
      SCWT(N) = 0.
      CWT (N) =0.
      SWT(N) = 0.
      ASWT(N) = 0.
      PSWT(N) = 0.
      APSWT(N) =0.
   10 CONTINUE
   20 READ 2,P1,I1,SC1,C1
      IP1 = ABSF(P1*4.+5.)
      IPHI(IP1) = I1
      SCWT(IP1) = SC1
      CWT(IP1) = C1
      IF (IP1 - IFIE)20,30,20
   30 N3 = 0
      L = 0
      DO 70 N1 = IFIS,IFIE
      IF (IPHI(N1)-1)80,110,90
   80 SWT(N1) = SCWT(N1) - CWT(N1)
      TSWT = TSWT + SWT(N1)
   85 IF (N3-0)130,130,140
  130 GO TO 70
   90 N3 = N3 + 1
      GO TO 70
  140 AN3 = N3 + 1
      SWT(N1) = SWT(N1)/AN3
      DO 120 N2 = 1,N3
      N7 = N1 - N2
  120 SWT(N7) = SWT(N1)
      N3 = 0
      GO TO 70
```

```
110 IF (L-1)150,160,160
150 PWT = (SCWT(N1) - CWT(N1) - DISP)*XMULT
    PIPWT = PWT
    N3 =0
    L = L +1
    GO TO 70
160 SWT(N1) = PWT - (SCWT(N1) - CWT(N1) - DISP)*XMULT
    PWT = PWT - SWT(N1)
    GO TO 85
 70 CONTINUE
    DO 170 N4 = IFIS,IFIE
    TOTWT = TOTWT + SWT(N4)
170 ASWT(N4) = TOTWT
    TOTWT = PIPWT + TSWT
    DO 180 N5=IFIS,IFIE
    PSWT(N5) = 100. * SWT(N5)/TOTWT
    TPWT = TPWT + PSWT(N5)
180 APSWT(N5) = TPWT
    DO 190 N6 = IFIS,IFIE
    PUNCH3,PHINO(N6),IPHI(N6),SCWT(N6),CWT(N6),SWT(N6),ASWT(N6),PSWT(N
   16),APSWT(N6),DATAID
190 CONTINUE
    PUNCH4,TOTWT,PIPWT,DATAID
    END
```

..I
..BRANCH 0040R

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 28 | 0.00 | 9.00 | .025 | 120 | RN1 |
| PHI | C | S+C | CONT | SWT | CWT | IPC | CPC |
| 0.00 | 0 | 9.1713 | 9.1645 | .0068 | .0068 | 0.00 | 0.00 |
| .25 | 2 | 0.0000 | 0.0000 | .0043 | .0111 | 0.00 | .01 |
| .50 | 0 | 9.1321 | 9.1235 | .0043 | .0154 | 0.00 | .01 |
| .75 | 2 | 0.0000 | 0.0000 | .0041 | .0195 | 0.00 | .01 |
| 1.00 | 0 | 9.1884 | 9.1802 | .0041 | .0236 | 0.00 | .02 |
| 1.25 | 2 | 0.0000 | 0.0000 | .0103 | .0339 | .01 | .03 |
| 1.50 | 0 | 9.1940 | 9.1734 | .0103 | .0442 | .01 | .04 |
| 1.75 | 2 | 0.0000 | 0.0000 | .1152 | .1594 | .11 | .16 |
| 2.00 | 0 | 9.4032 | 9.1728 | .1152 | .2746 | .11 | .27 |
| 2.25 | 2 | 0.0000 | 0.0000 | .6990 | .9736 | .70 | .98 |
| 2.50 | 0 | 10.5464 | 9.1483 | .6990 | 1.6727 | .70 | 1.68 |
| 2.75 | 2 | 0.0000 | 0.0000 | 2.7683 | 4.4410 | 2.79 | 4.48 |
| 3.00 | 0 | 14.7137 | 9.1771 | 2.7683 | 7.2093 | 2.79 | 7.28 |
| 3.25 | 0 | 15.3447 | 9.1620 | 6.1827 | 13.3920 | 6.24 | 13.52 |
| 3.50 | 0 | 10.6269 | 9.1770 | 1.4499 | 14.8419 | 1.46 | 14.98 |
| 3.75 | 0 | 11.1265 | 9.1678 | 1.9587 | 16.8006 | 1.97 | 16.96 |
| 4.00 | 0 | 10.4934 | 9.1707 | 1.3227 | 18.1233 | 1.33 | 18.30 |
| 4.25 | 1 | 9.8793 | 9.1802 | 0.0000 | 18.1233 | 0.00 | 18.30 |
| 4.50 | 1 | 9.8426 | 9.1734 | 3.5880 | 21.7113 | 3.62 | 21.92 |
| 4.75 | 2 | 0.0000 | 0.0000 | 4.2120 | 25.9233 | 4.25 | 26.18 |
| 5.00 | 1 | 9.7718 | 9.1728 | 4.2120 | 30.1353 | 4.25 | 30.43 |
| 5.25 | 2 | 0.0000 | 0.0000 | 6.6120 | 36.7473 | 6.67 | 37.11 |
| 5.50 | 1 | 9.6731 | 9.1843 | 6.6120 | 43.3593 | 6.67 | 43.79 |
| 5.75 | 2 | 0.0000 | 0.0000 | 4.2000 | 47.5593 | 4.24 | 48.03 |
| 6.00 | 1 | 9.5959 | 9.1771 | 4.2000 | 51.7593 | 4.24 | 52.27 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6.25 2 | 0.0000 | 0.0000 | 6.2400 | 57.9993 | 6.30 | 58.57 |
| 6.50 2 | 0.0000 | 0.0000 | 6.2400 | 64.2393 | 6.30 | 64.87 |
| 6.75 2 | 0.0000 | 0.0000 | 6.2400 | 70.4793 | 6.30 | 71.18 |
| 7.00 1 | 9.3728 | 9.1620 | 6.2400 | 76.7193 | 6.30 | 77.48 |
| 7.25 2 | 0.0000 | 0.0000 | 3.9870 | 80.7063 | 4.02 | 81.50 |
| 7.50 2 | 0.0000 | 0.0000 | 3.9870 | 84.6933 | 4.02 | 85.53 |
| 7.75 2 | 0.0000 | 0.0000 | 3.9870 | 88.6803 | 4.02 | 89.56 |
| 8.00 1 | 9.2549 | 9.1770 | 3.9870 | 92.6673 | 4.02 | 93.58 |
| 8.25 2 | 0.0000 | 0.0000 | .9930 | 93.6603 | 1.00 | 94.59 |
| 8.50 2 | 0.0000 | 0.0000 | .9930 | 94.6533 | 1.00 | 95.59 |
| 8.75 2 | 0.0000 | 0.0000 | .9930 | 95.6463 | 1.00 | 96.59 |
| 9.00 1 | 9.2126 | 9.1678 | .9930 | 96.6393 | 1.00 | 97.60 |

99.01    80.89    RN1

## APPENDIX B

### Calculation of Statistical Parameters

All the statistical parameters will be calculated for sample 29 to show the methods used. The formulas are found in Folk (1961).

Mode.

The mode is calculated from the cumulative curve (figure 8) by taking a point where the mode appears to be, then taking an interval of 0.12 phi centered on this point and counting the weight percent represented. This is done until a maximum value is obtained. For sample 29 the mode in the sand fraction is 3.00 phi and the mode in the ash fraction is 4.3 phi.

Graphic Mean ($M_Z$) (Folk)

The graphic mean is calculated from the cumulative curve by using the formula

$$M_Z = \frac{\emptyset\,16 + \emptyset\,50 + \emptyset\,84}{3}$$

$$= \frac{2.63 + 4.12 + 6.25}{3}$$

$$= 4.33\ \emptyset$$

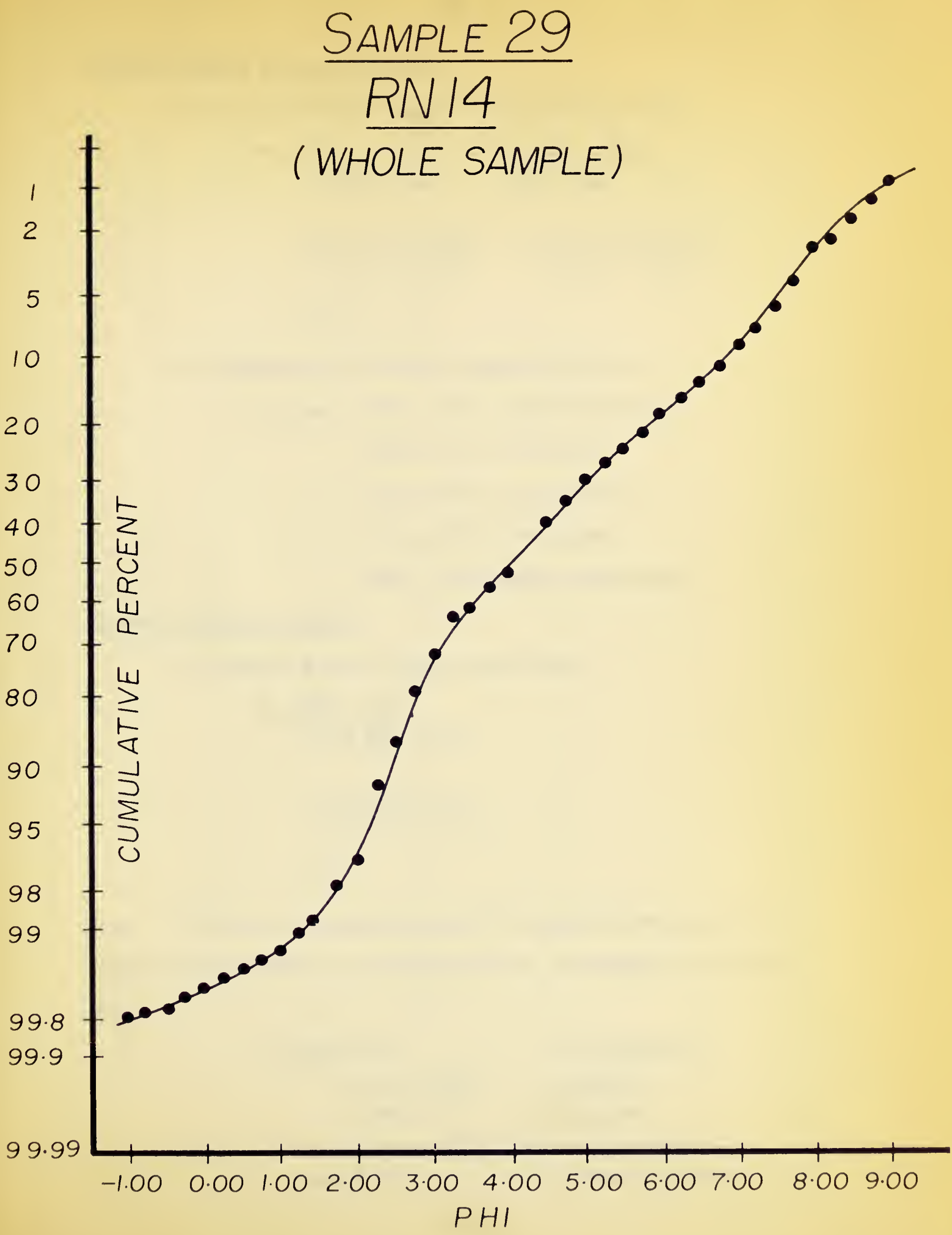
Inclusive Graphic Standard Deviation ($\sigma_I$) (Folk)

The Inclusive Graphic Standard Deviation is given by the formula

$$\sigma_I = \frac{\emptyset 84 - \emptyset 16}{4} + \frac{\emptyset 95 - \emptyset 5}{6.6}$$

$$= \frac{6.25 - 2.63}{4} + \frac{7.56 - 2.12}{6.6}$$

$$= 1.73\ \emptyset$$



SAMPLE 29
RN 14
(WHOLE SAMPLE)
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99·8
99·9
99·99
CUMULATIVE PERCENT
-1·00
0·00
1·00
2·00
3·00
4·00
5·00
6·00
7·00
8·00
9·00
PHI


FIGURE 8.

Inclusive Graphic Skewness ($SK_I$) (Folk)

The Inclusive Graphic Skewness is given by the formula

$$SK_I = \frac{\not{0}16 + 64 - 2\not{0}50}{2(\not{0}84 - \not{0}16} + \frac{\not{0}5 + \not{0}95 - 2\not{0}50}{2(\not{0}95 - \not{0}5)}$$

$$= \frac{2.63 + 6.25 - 8.24}{2(6.25 - 2.63)} + \frac{2.12 + 7.56 - 8.24}{2(7.56 - 2.12)}$$

$$= +.22$$

The following verbal limits are suggested by Folk:

| | | |
|---|---|---|
| $SK_I$ from | +1.00 to +.30 | strongly fine-skewed |
| | +.30 to +.10 | fine-skewed |
| | +.10 to -.10 | near-symetrical |
| | -.10 to -.30 | coarse-skewed |
| | -.30 to -1.00 | strongly coarse-skewed |

Graphic Kurtosis ($K_G$) (Folk)

The Graphic Kurtosis is given by the formula

$$K_G = \frac{\not{0}95 - \not{0}5}{2.44\ (\not{0}75 - \not{0}25)}$$

$$= \frac{7.56 - 2.12}{2.44\ (5.44 - 2.94)}$$

$$= .89$$

If the curve is excessively peaked it is called leptokurtic, if it is deficient or flat-peaked it is called platykurtic. The suggested verbal limits are:

| | | |
|---|---|---|
| $K_G$ under | 0.67 | very platykurtic |
| | 0.67 to 0.90 | platykurtic |
| | 0.90 to 1.11 | mesokurtic |
| | 1.11 - 1.50 - 3.00 | very leptokurtic |
| over | 3.00 | extremely leptokurtic |

TABLE 5

TABLE OF STATISTICAL PARAMETERS

| Sample No. | Computer Run No. | Mode (phi) | Graphic Mean ($M_z$) (phi) | Standard Deviation | Skewness (SKI) | Kurtosis (SKG) |
|---|---|---|---|---|---|---|
| 2-1 | 1 | 3.12 | 5.10 | 1.74 | -.049 | .77 |
| 2-2 | 2 | 3.12 | 5.15 | 1.77 | -.023 | .78 |
| 4 | 3 | 3.06 | 5.31 | 1.74 | -.12 | .89 |
| 5 | 4 | 3.06 | 5.29 | 1.85 | -.17 | .84 |
| 12 | 5 | 3.00 | 5.31 | 1.95 | -.34 | .72 |
| 17-1 | 6 | 2.94 | 4.79 | 2.12 | -.057 | .65 |
| 17-2 | 7 | 2.94 | 4.81 | 2.19 | -.022 | .67 |
| 23 | 8 | 2.25 | 5.07 | 2.17 | -.29 | .63 |
| 25-2 | 10 | 2.25 | 5.29 | 2.14 | -.25 | .70 |
| 25M | 11 | 2.44 | 2.72 | .38 | +.13 | .91 |
| 25H | 12 | 2.69 | 2.95 | .34 | +.017 | .87 |
| 28 | 13 | 3.06 | 5.54 | 1.75 | -.19 | .98 |
| 29 | 14 | 3.00 | 4.33 | 1.73 | +.22 | .89 |
| 32 | 15 | 2.12 | 2.10 | 0.62 | -.15 | 1.09 |
| 36 | 16 | 1.63 | 1.63 | 0.68 | -.080 | .95 |
| 36M | 17 | 3.19 | 3.18 | 0.26 | -.074 | 1.82 |
| 36H | 18 | 2.25 | 2.29 | 0.40 | +.087 | 1.00 |
| 40A | 19 | 1.69 | 1.86 | - | - | - |
| 40B | 20 | 1.38 | 1.60 | 0.31 | +.27 | 1.01 |
| 40C | 21 | 1.12 | .90 | 0.71 | -.22 | 1.12 |
| 41 | 22 | 1.25 | 1.04 | 0.65 | -.16 | .93 |
| 41M | 23 | 1.38 | 1.43 | 0.31 | +.096 | .96 |
| 41H | 24 | 1.87 | 1.76 | 0.35 | +.020 | .92 |

Table of Statistical Parameters Contd.

| | | | | | | |
|---|---|---|---|---|---|---|
| 43 | 25 | 1.25 | 2.62 | 2.60 | +.68 | 2.35 |
| 43M | 26 | 1.25 | 1.46 | 0.50 | +.39 | 1.68 |
| 43H | 27 | 2.25 | 1.97 | 0.55 | -.52 | .69 |
| 48-1 | 28 | 3.12 | 5.27 | 1.16 | -.21 | .89 |
| 48-2 | 29 | 3.12 | 5.39 | 1.96 | -.13 | .87 |
| 50 | 30 | 3.62 | 5.35 | 1.68 | -.10 | .88 |
| 63 | 31 | 3.19 | 4.64 | 1.87 | +.21 | .80 |
| 63M | 32 | 3.12 | 3.02 | 0.67 | -.13 | .93 |
| 63H | 33 | 3.19 | 3.25 | 0.49 | +.12 | 1.23 |
| 66 | 34 | 2.31 | 2.24 | 0.53 | -.069 | 1.02 |
| 9A | 35 | 3.06 | 5.41 | 2.20 | -.28 | .68 |
| 9AM | 36 | 3.12 | 2.76 | 5.25 | -.14 | 1.11 |
| 9AH | 37 | 3.06 | 3.08 | 0.36 | +.033 | 1.89 |
| 9B-1 | 38 | 3.06 | 5.46 | 1.75 | -.18 | 1.08 |
| 9BM | 39 | 3.19 | 3.39 | 0.45 | +.047 | 1.64 |
| 9BH | 40 | 3.31 | 3.54 | 0.37 | +.18 | .98 |
| 9B-2 | 41 | 3.06 | - | - | - | - |
| 9C-1 | 42 | 3.12 | 5.54 | 1.68 | -.24 | .99 |
| 9CM | 43 | 3.19 | 3.40 | 0.31 | +.44 | 1.14 |
| 9CH | 44 | 3.25 | 3.53 | 0.34 | +.018 | .90 |
| 9C-2 | 45 | 3.12 | 5.58 | 1.71 | -.24 | .96 |
| 9D-1 | 46 | 3.12 | 5.37 | 1.65 | -.26 | .75 |
| 9DM | 47 | 3.31 | 2.89 | - | - | - |
| 9DH | 48 | 3.50 | 3.56 | 0.30 | +.044 | .87 |
| 9D-2 | 49 | 3.19 | 5.42 | 1.68 | -.28 | .89 |

# APPENDIX C

## Calculation of Vent Location

The height of the cloud is determined from the pattern breadth by using the equation

$$Re = 15200\ W^{0.45}$$

and equation

$$H_T = 15200\ W^{0.1}$$

where Re is the effective radius in meters (1/2 the breadth of the pattern), W is the apparent yield in megatons of TNT and $H_T$ is the height of the top of the cloud in meters.

The 1/2 pattern breadth measured through sample 43 is 46 miles.

$\therefore$ Re = 46 miles = 74,028 meters if the approximation that the normal shear is zero is made.

Then,

$$Re = 15200\ W^{0.45}$$

$$W^{0.45} = \frac{74,028}{15,200}$$

$$W = 33.67 \text{ kilotons of TNT,}$$

and

$$H_T = 15200\ (33.67)^{.1}$$

$$H_T = 21600 \text{ meters.}$$

The mean height is calculated from

$$2 \Delta H = 0.44\ H_T,$$

where $2 \Delta H$ is the thickness of the cloud.

Then,

$$2 \Delta H = 0.44\ (21,600)$$

$\Delta H = 4{,}752$ meters.

Mean Height $= 21{,}600 - 4{,}752 = 16.848$

$= 16.8$ km (approx.)

The time down of the particles is calculated from Ksanda's formula,

$$V = 1.325 \log^3 (xd + 1.163)$$

where

$d$ = particle diameter in m.

$$x = \left( \frac{2g\ Po\ (P - Po)}{n^2} \right)^{1/3}$$

$$y = \left( \frac{Po^2}{2gn\ (P - Po)} \right)^{1/3}$$

where

$P$ = density in $kg/m^3$

$Po$ = air density in $kg/m^3$

$n$ = air viscosity kg/m second

$g$ = acceleration due to gravity $m/sec^2$.

The values for air were taken from the IACO Standard Atmosphere at sea level,

$d = 2.25 \times 10^{-4}$ m for sample 25

$= 1.25 \times 10^{-4}$ m for sample 41

$P = 2500\ kg/m^3$

$Po = 1.225\ kg/m^3$

$n = 1.78943 \times 10^{-5}$ kg/m sec.

$g = 9.80665\ m/sec^2$.

Then,

$$x = \left( \frac{2(9180665)\ (1.225)\ (2500 - 1.225)}{(1.78943 \times 10^{-5})^2} \right)^{1/3}$$

$$x = 57{,}230$$

and
$$y = \frac{(1.225)^2}{2(9.80665)\ (1.78943 \times 10^{-5})\ (2500 - 1.225)} \quad 1/3$$

$$= 1.196$$

The terminal velocity at sea level is then determined for sample 43 from

$$V = \frac{1.325}{Y} \log^3 (xd + 1.163)$$

$$= \frac{1.325}{1.196} \log^3 (57{,}230 \times 4.2 \times 10^{-4} + 1.163)$$

$$= 3.049 \text{ m per sec.}$$

The terminal velocity for sample 25 is calculated similarly to be

$$V = 1.556 \text{ m/sec.}$$

These sea level velocities are multiplied respectively by 1.60 and 1.35 to correct for altitude. These factors were determined from information given by McDonald (1960). Therefore the terminal mean velocity for sample 43 is 4.89 m/sec and for sample 25 is 2.09 m/sec.

The time down from the mean cloud height for sample 25 is 8,038 sec, and for sample 41 is 3,436 sec. The time difference is 4,602 secs. The distance between sample 43 and sample 25 is 118 miles. Therefore, the wind velocity is

$$\frac{118}{4602} = .0256 \text{ miles per sec.}$$

The distance of the vent from sample 43 is

$$D = .0256\ (3{,}436)$$

$$= 87.9$$

$$= 88 \text{ miles (approx.)}$$

# APPENDIX D

## Evaluation of Validity of Size Analyses

### Sieving

The normal precautions were taken to reduce errors in the sieve analysis. In sieving, in addition to the usual statistical errors, there are four types of errors due to the mass effect of the particles on the screen. They are: (1) errors due to effect of sieve loading; (2) errors due to effect of sieving time; (3) errors due to effect of random orientation of particles; (4) errors due to variations in the size of aperature.

There are various opinions on the relative importance of these errors and how to avoid them best. The suggestions of Herdan (1960) were followed in this thesis except for his suggestion for sieving time. He thought that more than 9 minutes is unnecessary, but this is much lower than times suggested by many workers, so it was decided to sieve for 20 minutes. He found from experiments that optimum conditions were obtained when 40 to 60 grams of fine sand were used and 100 to 150 grams of coarse sand. These loading weights were followed as closely as possible.

In order to test whether or not there was a large error due to sieving time, two samples containing appreciable amounts of fine sand were re-sieved on the Ro-Tap for two hours. The fraction resting on the 230 mesh screen was weighed and then compared to the value obtained from 20 minutes of sieving, the difference being taken as a measure of the maximum error in the sieve analysis. The results were as follows:

Sample 17,

2 hrs. sieving - 1.2665 gms
20 min. sieving - 1.0457 gms
difference = .2208 gms

percent overabundance of material in 20 minutes analysis $= \frac{.2208}{1.2665} \times 100 = 17.4\%$

Sample 29

2 hrs. sieving - 3.3751

20 min. sieving - 3.3181

difference = .0570

percent overabundance of material in 20 minutes

$$\text{analysis} = \frac{.2208}{1.2665} \times 100 = 1.7\%$$

These figures effectively give the maximum error in the analysis. In the case of sample p. 17, this error would increase the cumulative percent down to that size by 0.18% which is not critical. It is concluded therefore that there is a negligible error due to inadequate sieving time.

It was mentioned earlier in the text that enlarging of some aperatures in the 170 screen had been discovered. The other screens were also checked but they were found to be in order, so there is thought to be little error from this source in the rest of the analysis.

Pipette Method

The theoretical error in the pipette analysis is very small, approximately .04% (in Krumbeim, 1932), which is caused by the sampling of a small sphere around the tip of the pipette rather than an infinitesimal layer.

In practice however the error in absolute grain size may be fairly large as the particles in the suspension are not spheres. What is being measured is the sedimentation radius. Aside from the specific surface determinations no effort was made to convert the sedimentation radius to actual radius.

Some attempt was made to check the reproducibility of the data. Seven of the pipette analyses were run twice. To examine the results of these double runs it is best to look at the first two readings which determine the amount of material in the first size class. The individual weight percents in the first size class for the two runs on each sample are listed in table 6 and the difference between them shown.

TABLE 6

Table showing the reproducibility of the first size-class in the pipette analyses.

| Sample number | Run 1 (Wt. %) | Run 2 (Wt. %) | Difference (Wt. %) |
|---|---|---|---|
| 2 | 4.44 | 5.28 | 0.84 |
| 17 | .46 | 2.93 | 2.47 |
| 25 | -.83 | 3.47 | 4.30 |
| 48 | 6.75 | 4.57 | 2.18 |
| 9B | 0.00 | -.43 | .43 |
| 9C | .47 | 2.58 | 2.11 |
| 9D | 4.10 | 2.25 | 1.85 |
| | | Average | 2.03 |

As is seen from the table, the maximum difference is 4.3% and the average difference for the seven samples is only 2.03%. Ordinarily, the reproducibility in using the pipette method is thought to be in the order of ± 2 to 5% (Herdan 1960), so the results obtained here would appear to be somewhat better than usual. This improvement is attributed to the Shaw pipette rack and the Lowy automatic pipette.

The reproducibility improves with later readings. For example, in sample 25 the difference in the 4.5 to 5.0 phi class is 2.98% and in the 5 to 5.5 phi class is 1.72%, after which it is fairly constant. When this trend was noticed special effort was made to try to improve the reproducibility of the first size class. Therefore, in later analyses three separate aliquots were taken for the first sample and two were taken for the second. The maximum readings for each of these two sets of samples were used in the calculations. It was not feasible to check the reproducibility of these readings as too much of the material was being removed from the suspension and it was feared that the distribution would suffer. However, on a statistical basis this procedure should have increased the accuracy of the first size-class considerably.

# APPENDIX E

## WITHDRAWAL TIMES FOR 22°C. S.G. 2.439, 4 SUSPENSIONS

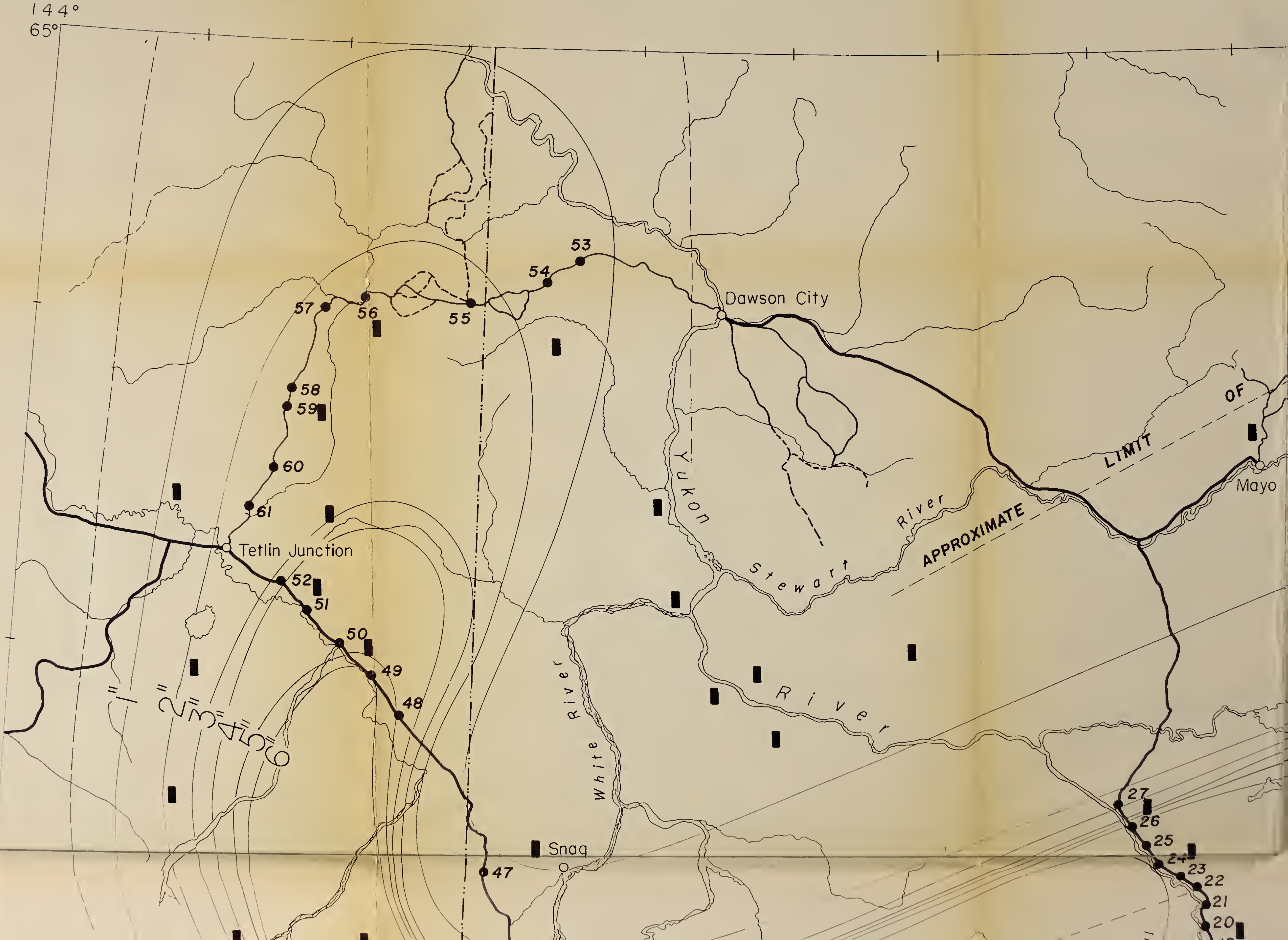
Sample depth 10 cm. except for sample #8 which is 5 cm.

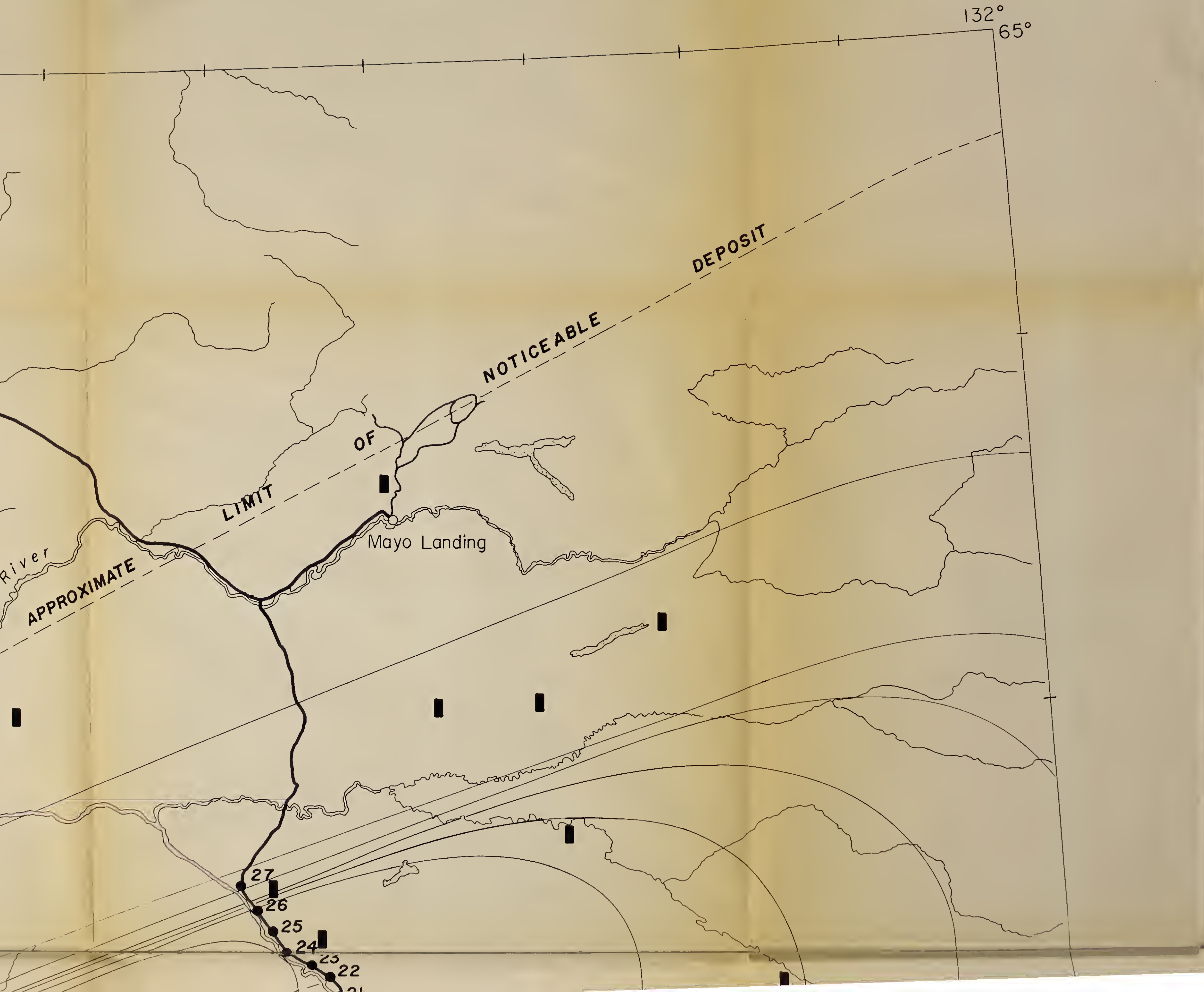
| | | | | |
|---|---|---|---|---|
| 0 sec – | start suspension | #1 | | |
| 15 sec – | withdraw sample | (1) | from suspension | #1 |
| 1 min 3 sec – | " | (2) | " | #1 |
| 2 min 7 sec – | " | (3) | " | #1 |
| 4 min 10 sec – | " | (4) | " | #1 |
| 8 min 23 sec – | " | (5) | " | #1 |
| 10 min 0 sec – | start suspension | #2 | | |
| 10 min 15 sec – | withdraw sample | (1) | " | #2 |
| 11 min 3 sec – | " | (2) | " | #2 |
| 12 min 7 sec – | " | (3) | " | #2 |
| 14 min 10 sec – | " | (4) | " | #2 |
| 18 min 23 sec – | " | (5) | " | #2 |
| 20 min 0 sec – | start suspension | #3 | | |
| 20 min 15 sec – | withdraw sample | (1) | " | #3 |
| 21 min 3 sec – | " | (2) | " | #3 |
| 22 min 7 sec – | " | (3) | " | #3 |
| 24 min 10 sec – | " | (4) | " | #3 |
| 28 min 23 sec – | " | (5) | " | #3 |
| 30 min 0 sec – | start suspension | #4 | | |
| 30 min 15 sec – | withdraw sample | (1) | " | #4 |
| 31 min 3 sec – | " | (2) | " | #4 |
| 32 min 7 sec – | " | (3) | " | #4 |
| 33 min 30 sec – | " | (3) | " | #1 |
| 34 min 10 sec – | " | (4) | " | #4 |
| 38 min 23 sec – | " | (5) | " | #4 |
| 43 min 30 sec – | " | (6) | " | #2 |
| 53 min 30 sec – | " | (6) | " | #3 |
| 1 hr 3 min 30 sec – | " | (6) | " | #4 |
| 2 hr 14 min 1 sec – | " | (7) | " | #1 |
| 2 hr 24 min 1 sec – | " | (7) | " | #2 |
| 2 hr 34 min 1 sec – | " | (7) | " | #3 |
| 2 hr 44 min 1 sec – | " | (7) | " | #4 |
| 4 hr 14 min 32 sec – | " | (8) | " | #1 |
| 4 hr 24 min 32 sec – | " | (8) | " | #2 |
| 4 hr 34 min 32 sec – | " | (8) | " | #3 |
| 4 hr 44 min 32 sec – | " | (8) | " | #4 |

TIMES OF WITHDRAWAL FOR 20°C, S.G. 2.439, 4 SUSPENSIONS

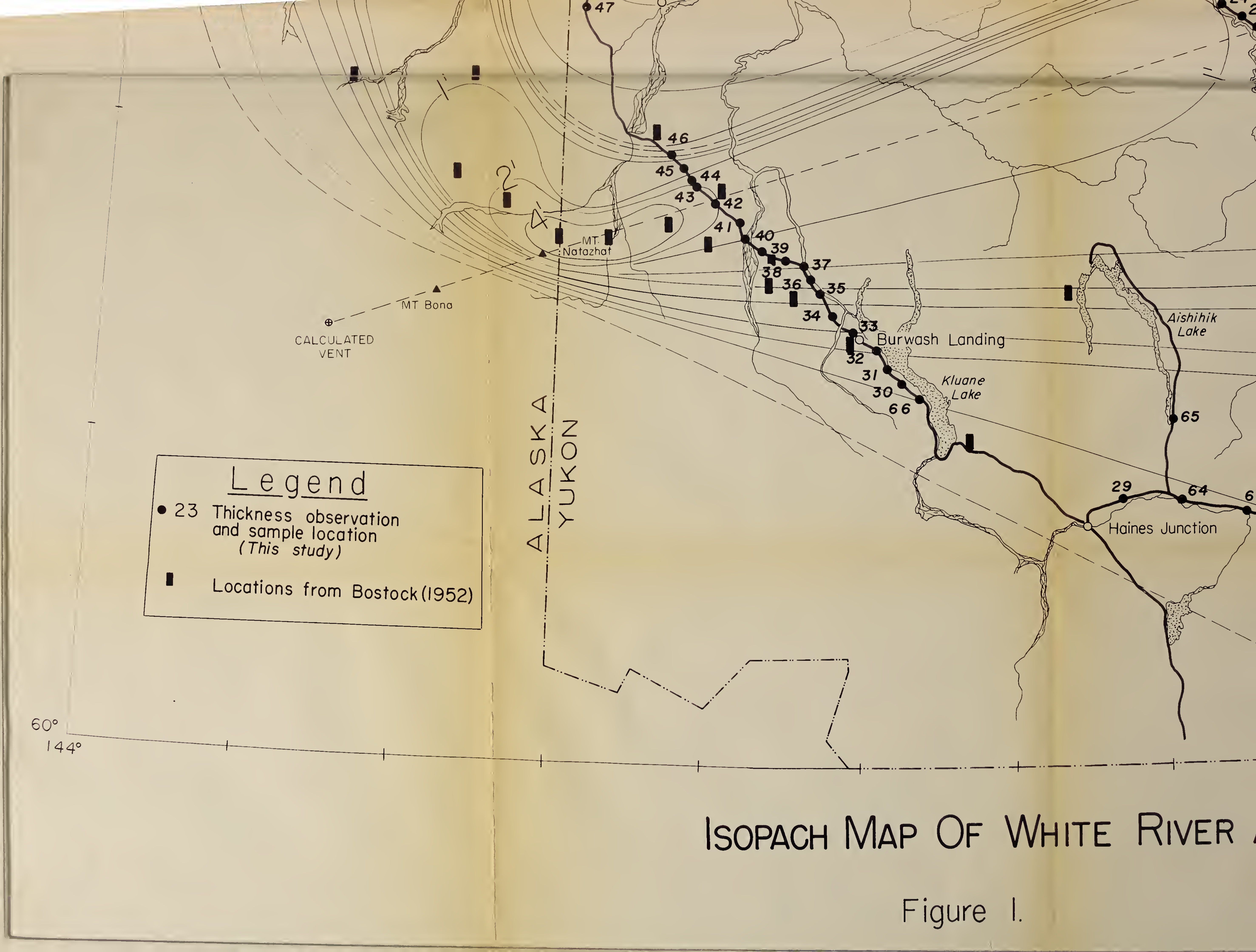
Sample depth is 10 cm. except for sample #8 which is 5 cm.

| | | | | |
|---|---|---|---|---|
| 0 min 0 sec – | start suspension | #1 | | |
| 0 min 15 sec – | withdraw sample | (1) | from suspension | #1 |
| 1 min 6 sec – | " | (2) | " | #1 |
| 2 min 14 sec – | " | (3) | " | #1 |
| 4 min 23 sec – | " | (4) | " | #1 |
| 8 min 48 sec – | " | (5) | " | #1 |
| 10 min 0 sec – | start suspension | #2 | | |
| 10 min 15 sec – | withdraw sample | (1) | " | #2 |
| 11 min 6 sec – | " | (2) | " | #2 |
| 12 min 14 sec – | " | (3) | " | #2 |
| 14 min 23 sec – | " | (4) | " | #2 |
| 18 min 48 sec – | " | (5) | " | #2 |
| 20 min 0 sec – | start suspension | #3 | | |
| 20 min 15 sec – | withdraw sample | (1) | " | #3 |
| 21 min 6 sec – | " | (2) | " | #3 |
| 22 min 14 sec – | " | (3) | " | #3 |
| 24 min 23 sec – | " | (4) | " | #3 |
| 28 min 48 sec – | " | (5) | " | #3 |
| 30 min 0 sec – | start suspension | #4 | | |
| 30 min 15 sec – | withdraw sample | (1) | " | #4 |
| 31 min 6 sec – | " | (2) | " | #4 |
| 32 min 14 sec – | " | (3) | " | #4 |
| 34 min 23 sec – | " | (4) | " | #4 |
| 35 min 10 sec – | " | (6) | " | #1 |
| 38 min 48 sec – | " | (6) | " | #4 |
| 45 min 10 sec – | " | (6) | " | #2 |
| 55 min 10 sec – | " | (6) | " | #3 |
| 1 hr 5 min 10 sec – | " | (6) | " | #4 |
| 2 hr 20 min 42 sec – | " | (7) | " | #1 |
| 2 hr 30 min 42 sec – | " | (7) | " | #2 |
| 2 hr 40 min 42 sec – | " | (7) | " | #3 |
| 2 hr 50 min 42 sec – | " | (7) | " | #4 |
| 4 hr 28 min – | " | (8) | " | #1 |
| 4 hr 38 min – | " | (8) | " | #2 |
| 4 hr 48 min – | " | (8) | " | #3 |
| 4 hr 58 min – | " | (8) | " | #4 |


144°
65°
Dawson City
Tetlin Junction
Mayo
Snag
Yukon
Stewart River
White River
River
APPROXIMATE LIMIT OF
1 2 3 4 5 6
20 21 22 23 24 25 26 27
47 48 49 50 51 52 53 54 55 56 57 58 59 60 61

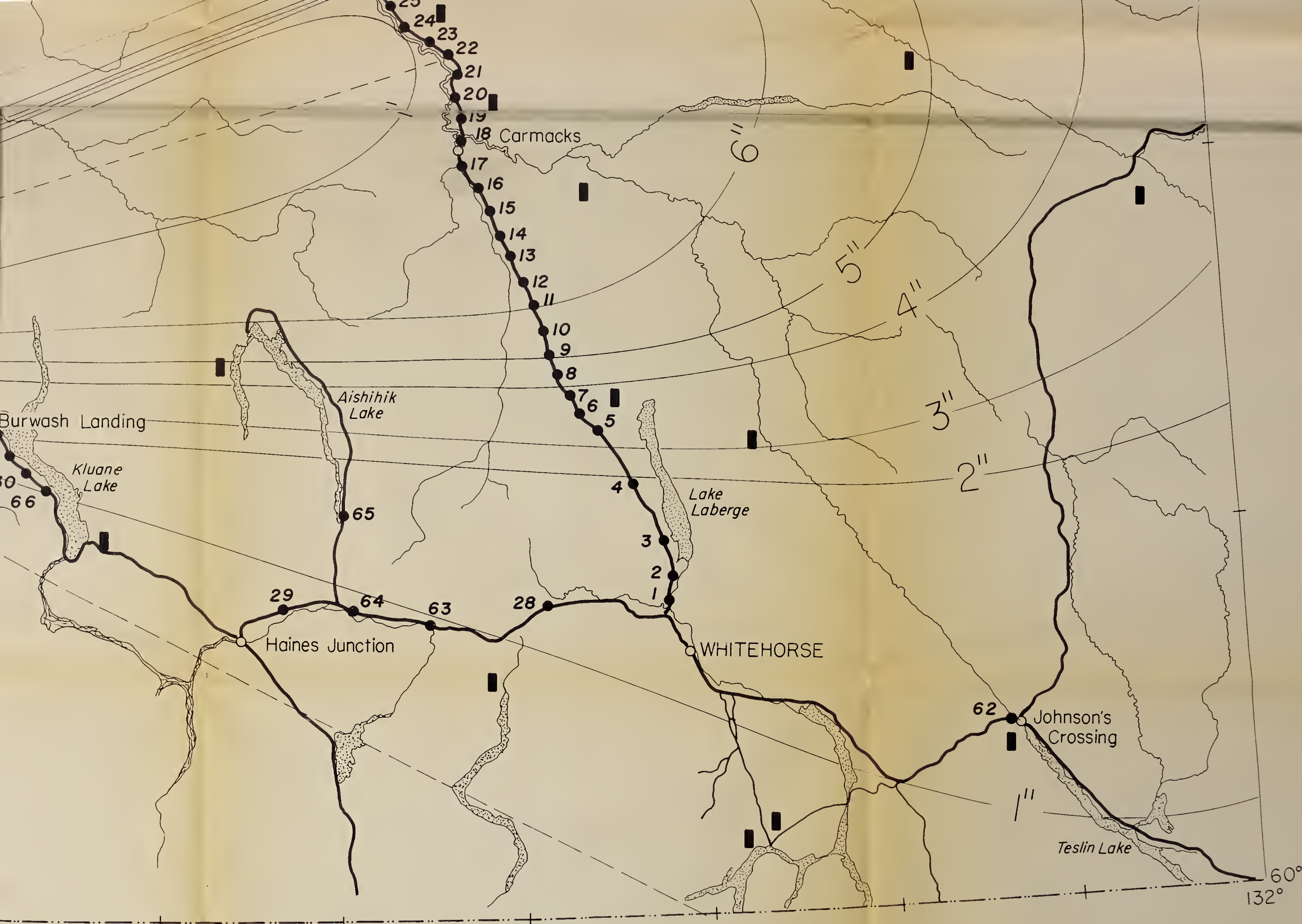


132°
65°
APPROXIMATE LIMIT OF NOTICEABLE DEPOSIT
River
Mayo Landing
27
26
25
24
23
22




ISOPACH MAP OF WHITE RIVER

Figure I.




# AP OF WHITE RIVER ASH

Figure 1.